EPA

United States
Environmental Protection
Agency

Long Term 1 Enhanced Surface Water Treatment Rule Turbidity Provisions
Technical Guidance Manual

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ABBREVIATIONS AND ACRONYMS

ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
AWOP	Area Wide Optimization Program
AWWA	American Water Works Association
CCP	Composite Correction Program
CFE	Combined Filter Effluent
CFR	Code of Federal Regulations
CPE	Comprehensive Performance Evaluation
CTA	Comprehensive Technical Assistance
DBP	Disinfection By-Products
DBPR	Disinfection By-Products Rule
DE	Diatomaceous Earth
EPA	Environmental Protection Agency
FBRR	Filter Backwash Recycling Rule
fps	feet per second
gal	gallons
GLI	Great Lakes International
gpm	gallons per minute
gpm/ft^2	gallons per minute per square foot
GWUDI	Groundwater Under Direct Influence of Surface Water
HAA5	Haloacetic Acids (monochloroacetic, dichloroacetic, trichloroacetic, monobromoacetic, and dibromoacetic acids)
hrs	Hours
IESWTR	Interim Enhanced Surface Water Treatment Rule
IFE	Individual Filter Effluent
LT1ESWTR	Long-Term 1 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MG	Million Gallons
mg/l	milligrams per liter

MGD	Million Gallons per Day
m/h	meters per hour
M/R	Monitoring/Reporting
MSDS	Material Safety Data Sheet
NTU	Nephelometric Turbidity Unit
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Association
PWS	Public Water System
PWSID	Public Water System Identification
QA/QC	Quality Assurance/Quality Control
RO	Reverse Osmosis
SCADA	Supervisory Control and Data Acquisition System
SCU	Solids Contact Unit
SDWA	Safe Drinking Water Act
SOP	Standard Operating Procedure
TOC	Total Organic Carbon
TTHM	Total Trihalomethanes
TVT	Triple Validation Turbidimeter
WTP	Water Treatment Plant
μ	Micro
μm	Micron
μg/L	Micrograms per liter

MARGIN ICONS

Icons and text have been placed in the margins of this document to highlight information and additional resources. These icons are shown below with brief descriptions of their uses or the types of information they may be used to highlight.

Indicates a reference to the federal regulations.

Indicates the need to consult with the State.

Indicates additional references or highlights important information.

Indicates worksheets.

Indicates sampling or data collection requirements.

Indicates applicability criteria.

Indicates a helpful hint or suggestion.
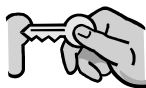
Highlights a key point or key information.

Indicates that the system should be careful.

1. INTRODUCTION

In this Chapter:
- Purpose of Document
- Overview of LT1ESWTR
- Overview of Turbidity Requirements
- Other Applicable Rules
- Summary of Chapters

40 CFR Section 141.501

1.1 PURPOSE OF DOCUMENT

This document provides information on the combined filter effluent and individual filter effluent requirements in the Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR).

Copies of this document and other referenced documents can be obtained by:

- Contacting the appropriate State office.

- Calling the Safe Drinking Water Hotline at 1-800-426-4791.

- Downloading from EPA's Web site at http://www.epa.gov/safewater/mdbp/lt1eswtr.html.

- Calling the National Service Center for Environmental Publications at 1-800-490-9198 or visiting its Web site at http://www.epa.gov/ncepihom/.

Systems serving 10,000 or more persons should refer to the Interim Enhanced Surface Water Treatment Rule Documents. For more information see http://www.epa.gov/safewater/mdbp/implement.html.

Key components of LT1ESWTR

1.2 OVERVIEW OF LT1ESWTR

The LT1ESWTR is a Federal regulation that establishes a treatment technique to control *Cryptosporidium*. The rule applies to public water systems serving fewer than 10,000 persons and classified as either a surface water system or a ground water system under the direct influence of surface water (GWUDI). Key components of the LT1ESWTR are:

Key components of
LT1ESWTR (cont.)

The term "State" as used in
this document means both
State and Primacy Agency.
The Glossary in Appendix
A contains the definition
for "State."

40 CFR Section 141.502
Systems must begin
complying with
LT1ESWTR turbidity
provisions by January 1,
2005. The compliance
date was changed from
January 14, 2005, to
January 1, 2005 (69 FR
38850; June 29, 2004).

- Systems that filter their water must provide a minimum of 2-log removal of *Cryptosporidium.*

- Systems using conventional or direct filtration plants must meet more stringent combined filter effluent turbidity limits and must meet new requirements for individual filter effluent turbidity.

- Systems using alternative filtration techniques (defined as filtration other than conventional, direct, slow sand, or diatomaceous earth) must demonstrate to the State the ability to consistently achieve 2-log removal of *Cryptosporidium* and comply with specific State-established combined filter effluent turbidity requirements.

- Systems that meet the filtration avoidance criteria must comply with watershed control requirements to address *Cryptosporidium.*

- Systems must develop a disinfection profile unless the State determines that the disinfection profile is unnecessary. The State can only make this determination if the system can demonstrate that the levels of Total Trihalomethanes (TTHM) and Haloacetic Acids (HAA5) are below 0.064 mg/L and 0.048 mg/L, respectively. Systems must develop a disinfection benchmark if the system plans to make a significant change to disinfection practices. For more information on the LT1ESWTR disinfection profiling and benchmarking requirements, refer to *LT1ESWTR Disinfection Profilng and Benchmarking Technical Guidance Manual* (EPA 816-R-03-004, 2003).

- New, finished water reservoirs must be covered.

- *Cryptosporidium* is now included in the Federal definition of GWUDI.

1.3 OVERVIEW OF TURBIDITY PROVISIONS

Systems must begin complying with the turbidity provisions in the LT1ESWTR by January 1, 2005.

The LT1ESWTR establishes combined filter effluent turbidity requirements for conventional and direct filtration plants to accomplish a 2-log removal of *Cryptosporidium.* These limits are more stringent than the combined filter effluent limits

established for *Giardia* in 40 CFR Section 141.73. More stringent limits were not set for slow sand and diatomaceous earth filtration systems because data indicate that these technologies are able to achieve 2-log *Cryptosporidium* removal with the turbidity limits set in the Surface Water Treatment Rule. Alternative filtration systems (defined as filtration systems other than conventional, direct, slow sand, and diatomaceous earth filtration) must meet State-specified combined filter effluent turbidity requirements and conduct a demonstration study that demonstrates the system's filtration and disinfection treatment removes specified levels of *Cryptosporidium*, *Giardia*, and viruses.

The combined filter effluent may meet regulatory requirements for the combined filter effluent turbidity even though one filter is producing high-turbidity water (see Figure 1-1). Consequently, one poorly performing filter can create a health risk by passing pathogens, including *Cryptosporidium*. Because properly functioning filters can mask the poor performance of another filter, **the LT1ESWTR also requires continuous monitoring of turbidity for each individual filter (recorded at least once every 15 minutes) for conventional and direct filtration systems**.

Adequate filtration is the main defense against *Cryptosporidium*.

Figure 1-1 Illustrating the need to monitor individual filters.

Filter #1	Filter #2	Filter #3	Filter #4
0.05 NTU	0.05 NTU	0.05 NTU	1.1 NTU

To Clearwell

Combined Filter Effluent = 0.30 NTU
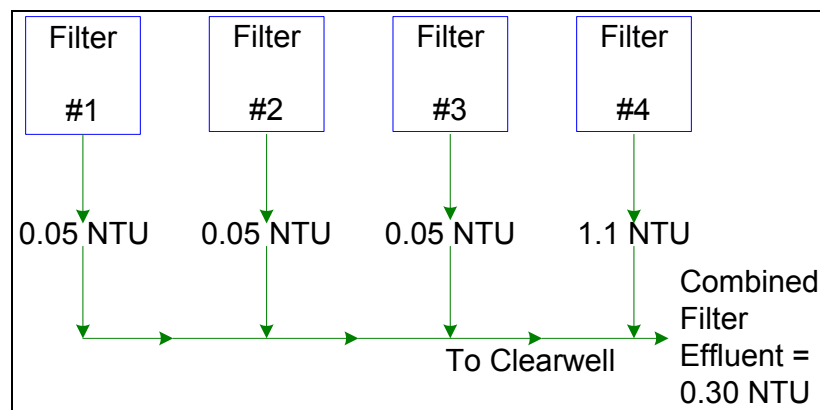
Figure 1-1. Example of a poorly performing filter (Filter #4) being masked by properly performing filters (Filters #1, #2, and #3). Note that the combined filter effluent turbidity does not exceed the regulatory standard for combined filter effluent.

The pathogens can then travel through the remaining treatment plant processes and eventually reach customers, creating a health risk. *Cryptosporidium* is of particular concern because it is resistant to commonly used disinfectants, such as chlorine, and, therefore, should be removed by the treatment process.

As explained in the chapters that follow, monitoring and reporting requirements vary according to the type of filtration technology used. Worksheets provided in Appendix B can be used to record and report data to the State. Systems will want to check with their State office to make sure the worksheets are acceptable for reporting data to the State.

1.4 OTHER APPLICABLE RULES

Two other rules may also affect the treatment practices of systems regulated by LT1ESWTR:

1) Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR).

   Surface water systems serving fewer than 10,000 persons and all ground water systems that use a chemical disinfectant must begin complying with the Stage 1 DBPR by **January 1, 2004**. This rule requires monitoring of disinfection residuals and disinfection byproducts. More information on this rule is available at http://www.epa.gov/safewater/mdbp/implement.html.

2) Filter Backwash Recycling Rule (FBRR).

   The FBRR was published by EPA on June 8, 2001, and affects systems that meet all of the following criteria:

   - The system is a surface water system or GWUDI system.

   - The system treats water using conventional or direct filtration.

   - The system recycles one or more of the following: spent filter backwash, thickener supernatant, or liquids from dewatering devices.

Affected systems were required to report information about their system to the State by December 8, 2003. The FBRR also

DBPR = Disinfection Byproducts Rule

FBRR = Filter Backwash Recycling Rule

More information on the FBRR is available in the *FBRR Technical Guidance Manual* (EPA 816-R-02-014) or on EPA's Web site (http://www.epa.gov/safewater/filterbackwash.html).

requires regulated recycle streams to be returned through all processes of a system's existing conventional or direct filtration system or at an alternate location approved by the State. In addition, the FBRR has recordkeeping requirements for affected systems.

Contents of Document

1.5 SUMMARY OF CHAPTERS

This document is organized in the following sections and chapters:

- **Chapter 1 - Introduction**

- **Chapter 2 - Turbidity Requirements**

  This chapter presents the turbidity monitoring, reporting, and recordkeeping requirements for conventional, direct, slow sand, diatomaceous earth, and alternative filtration technologies.

- **Chapter 3 – Turbidity Sampling Methods and Turbidimeters**

  This chapter presents information on approved turbidity sampling methods, and on the operation, maintenance, and calibration of turbidimeters.

- **Chapter 4 – Data Collection and Management**

  This chapter provides information and tools for collecting and managing turbidity data. Worksheets are presented that can be used for recording and reporting data to the State.

- **Chapter 5 – Filter Self-Assessment**

  This chapter provides a thorough explanation of the filter self-assessment process, including analyses of a typical filter profile, hydraulic loading, backwash practices, examining filter media, and other issues related to the filter.

- **Chapter 6 – Comprehensive Performance Evaluation (CPE)**

  This chapter briefly describes the CPE process and when a CPE is required. Systems can obtain detailed information on the CPE process in the EPA Handbook *Optimizing Water Treatment Plant Performance Using the Composite Correction Program*, 1998 Edition (EPA 625-6-91-027).

Contents of Document

- **Chapter 7 - Turbidity and the Treatment Process**

  This chapter explains why turbidity is used as a measurement for treated water quality and why pathogens must be removed and/or inactivated. It also discusses the treatment processes used to remove and/or inactivate pathogens.

- **Chapter 8 – Treatment Optimization**

  This chapter describes how types of coagulation chemicals and their feed rates, pH, source water characteristics, and other factors influence the treatment process. Guidelines are provided for the type and typical doses of chemicals to be used to optimize the treatment process.

Appendices

- **Appendix A – Glossary**

- **Appendix B – Worksheets**

- **Appendix C – Equations and Sample Calculations**

- **Appendix D – Suggested Backwash Rates**

- **Appendix E – Filter Self-Assessment Example Report**

- **Appendix F – Jar Tests**

- **Appendix G – Example of an Operating Procedure for Chemical Feed System**

- **Appendix H – Example of an Operating Procedure for Filters**

2. TURBIDITY REQUIREMENTS

40 CFR Sections
141.74(c)(1) and 141.551

2.1 WHAT ARE THE TURBIDITY REQUIREMENTS FOR CONVENTIONAL AND DIRECT FILTRATION SYSTEMS?

The LT1ESWTR requirements for combined filter effluent monitoring are more stringent than those of the Surface Water Treatment Rule, and the LT1ESWTR has new requirements for individual filter effluent turbidity monitoring for conventional and direct filtration plants. These new turbidity monitoring requirements were established to control *Cryptosporidium*. Systems must comply with the LT1ESWTR requirements by January 1, 2005, except where otherwise noted.

2.1.1 Combined Filter Effluent Turbidity

Combined filter effluent is generated when the effluent water from individual filters in operation is combined into one stream. Figure 2-1 is a flowchart that summarizes the requirements for combined filter effluent monitoring for conventional and direct filtration plants.

Monitoring Requirements

Combined filter effluent turbidity must be measured every 4 hours during plant operation. The combined filter effluent turbidity for conventional and direct filtration systems must be less than or equal to 0.3 nephelometric turbidity unit (NTU) for 95 percent of the readings taken each month and may at no time exceed 1 NTU (based on turbidity measurements recorded every 4 hours). The frequency of monitoring may be reduced for systems serving 500 or fewer persons to once per day if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance.

Systems will want to check with their State on combined filter effluent requirements because the State may require additional monitoring.

40 CFR Section 141.570

Conventional filtration, as defined in 40 CFR Section 141.2, is a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal.

Direct filtration, as defined in 40 CFR Section 141.2, is a series of processes including coagulation and filtration, but excluding sedimentation, that result in substantial particulate removal.

Reporting and Recordkeeping Requirements

Monthly reports on turbidity from conventional and direct filtration systems due to the State by the 10th of the following month must contain:

- Total number of combined filter effluent turbidity measurements taken during the month.

- The number and percentage of combined filter effluent turbidity measurements taken during the month which were less than or equal to the system's required 95th percentile limit of 0.3 NTU.

- The date and value of any combined filter effluent turbidity measurement taken during the month that exceeded 1 NTU.

As required by the Public Notification Rule (40 CFR Section 141.203(b)(3)), if the combined filter effluent exceeds 1 NTU at any time, the system must consult the Primacy Agency within 24 hours. Systems also need to provide public notification of violations of the 95th percentile limit as soon as practical, but no later than 30 days after the system learns of the violation (Tier 2 Public Notice).

Figure 2-1. Combined Filter Effluent Provisions of the LT1ESWTR
for Systems Using Conventional or Direct Filtration

Does the system use either surface water or GWUDI, filter, and serve fewer than 10,000 persons?

No → No combined filter effluent requirements under LT1ESWTR

Yes ↓

Does the system use conventional or direct filtration?

No → System must comply with combined filter effluent provisions for either slow sand, diatomaceous earth or alternative filtration.

Yes ↓

All systems using conventional or direct filtration must comply with combined filter effluent requirements (§ 141.550).

↓

Did the system monitor combined filter effluent turbidity at 4-hour intervals?[1]

No → M/R Violation[4]

Yes ↓

Was turbidity less than or equal to 0.3 NTU in at least 95% of the measurements taken for the month (§ 141.551(a))?

No → TT Violation[4]

Yes ↓

Did turbidity exceed 1 NTU at any time (§ 141.551(b))?[2]

Yes → TT Violation[4]

No ↓

Did the system report combined filter effluent measurements to the State by the 10th of each month?[3]

Yes → Relevant monthly reporting requirements satisfied

No → M/R Violation[4]

1. As per the SWTR, 40 CFR Section 141.74 (c)(1), the State may reduce this monitoring frequency for systems serving 500 or fewer persons to one sample per day if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance.
2. System must consult with the Primacy Agency no later than 24 hours after learning of the violation in accordance with the Public Notification Rule (40 CFR Section 141.203(b)(3)).
3. Systems must report to the State the total number of combined filter effluent turbidity measurements taken during the previous month, the number and percentage of turbidity measurements that were less than or equal to 0.3 NTU, and date and value of any turbidity measurements exceeding 1 NTU (40 CFR Section 141.570(a)).
4. Public notification is required per Appendix A to Subpart Q of 40 CFR Section 141.

2.1.2 Individual Filter Effluent Turbidity

Filtration is one of the most critical treatment processes for particle and pathogen removal. The LT1ESWTR requires Subpart H systems using conventional or direct filtration to conduct continuous monitoring of the turbidity of individual filters to provide information on each filter's performance. Performance problems, indicated by an exceedance of certain turbidity limits for specified time periods, trigger follow-up actions. Follow-up actions vary from notification of the Primacy Agency to having a Comprehensive Performance Evaluation (CPE). Figure 2-2 summarizes the individual filter monitoring and reporting requirements.

Monitoring Requirements

Under LT1ESWTR, if a system only consists of two or fewer filters, it may conduct continuous monitoring of combined filter effluent turbidity in lieu of individual filter effluent turbidity. As a practical matter, this means if a system has only one filter, filter effluent turbidity must be continuously monitored and recorded at least every 15 minutes. Systems that have two filters are not required to monitor individual filters if the combined filter effluent turbidity from both filters is continuously monitored and recorded at least every15 minutes. (Systems should check with their State to see if this is acceptable.) Otherwise, the system is required to continuously monitor and record individual filter effluent turbidity at least every 15 minutes. If a system has three or more filters, each individual filter effluent turbidity must be monitored and recorded. Regardless of the number of filters, all systems must record and report the combined filter effluent in accordance with 40 CFR Sections 141.551 and 141.570 (see Section 2.1.1 of this document). Follow-up actions are triggered based on exceedances of 15-minute interval values (even if readings are taken more frequently for operational purposes). It is important to note that State regulations for individual filter monitoring and reporting may be more stringent. A brief summary of LT1ESWTR monitoring requirements for the specified number of filters is shown in Table 2-1. Figure 2-3 also provides an illustration of individual and combined filter turbidity monitoring requirements.

40 CFR Sections 141.560-563 For systems subject to these requirements, individual filter effluent turbidity must be continuously monitored and results must be recorded at least every 15 minutes.

Table 2-1. LT1ESWTR Combined and Individual Filter Effluent Turbidity Monitoring Requirements for Conventional and Direct Filtration Systems

Number of Filters	Monitoring Requirements
1	Individual filter effluent turbidity continuously monitored and recorded at least every 15 minutes. In addition, 4-hour turbidity readings must be recorded. Monthly reports must be provided in accordance with 40 CFR Sections 141.551 and 141.570.
2	Combined filter effluent turbidity continuously monitored and recorded at least every 15 minutes or individual filter effluent turbidity recorded at least every 15 minutes. In addition, combined filter effluent turbidity must be recorded every 4 hours and monthly reports provided in accordance with 40 CFR Sections 141.551 and 141.570.
More Than 2	Individual filters are continuously monitored and the results are recorded at least every 15 minutes. In addition, combined filter effluent turbidity must be recorded every 4 hours and monthly reports provided in accordance with 40 CFR Sections 141.551 and 141.570.

The following also apply to continuous individual filter turbidity monitoring (or for systems with two or fewer filters that monitor combined filter effluent continuously):

- In the event of the failure of continuous turbidity monitoring equipment, the system must conduct grab sampling every 4 hours until the equipment is replaced or repaired. The system has 14 days to resume continuous monitoring.

- Monitoring must be conducted using an approved method listed in 40 CFR Section 141.74(a). Approved methods are EPA Method 180.1, Standard Method 2130B, Great Lakes Instrument Method 2, and Hach FilterTrak Method 10133. Turbidimeters must conform to one of these methods. More information on turbidity sampling, including the approved methods mentioned here, is provided in Chapter 3 of this manual.

- Calibration of turbidimeters must be conducted using procedures specified by the manufacturer.

- Systems must keep records from individual filter turbidity monitoring for at least 3 years.

Individual filter effluent turbidimeters must use EPA Method 180.1, Standard Method 2130B, Great Lakes Instrument Method 2, or Hach FilterTrak Method 10133.

Figure 2-2. Individual Filter Effluent Turbidity Provisions of the LT1ESWTR for Systems Using Conventional or Direct Filtration
Part 1. Individual Filter Effluent Monitoring Provisions

1. Systems with two or fewer filters may conduct continuous monitoring of combined filter effluent in lieu of individual filter effluent turbidity monitoring.

2. Monitoring must be conducted using an approved method in 40 CFR Section 141.74(a). Calibration of turbidimeters must be conducted using procedures specified by the manufacturer.

3. System has an M/R violation until the relevant requirement is completed (such as conducting a filter self-assessment). Public notification is required per Appendix A to Subpart Q of 40 CFR Section 141.

4. For systems with two or fewer filters, combined filter effluent can be substituted for individual filter effluent (see footnote 1). If a filter self-assessment is triggered, the self-assessment must be conducted on both filters.

**Figure 2.2 (cont.) Individual Filter Effluent Turbidity Provisions of the LT1ESWTR
for Systems Using Conventional and Direct Filtration
Part 2. Individual Filter Effluent Turbidity Exceedance Follow-up Actions**

From Part 1
(previous page)

M/R VIOLATION[3]
(Return to previous
diamond and complete
requirement)

Did any
individual filter turbidity
measurement from the same
filter exceed 1.0 NTU for 2
consecutive 15-minute
readings?[4]

NO

YES

Did the
system conduct self-
assessment within
14 days?

NO

YES

Did the
system report
that the self-
assessment was
conducted?

NO

YES

Did
the system
arrange for
a CPE with the
State within 60
days of
exceedance?

NO

YES

Was
evaluation
completed and
submitted to
State within
120
days?

NO

YES

System must conduct
a self-assessment of the
filter within 14 days of
the exceedance and report
that self-assessment
was conducted unless a
CPE is required.[4]

System must arrange to have
State or State-approved third
party conduct a Comprehensive
Performance Evaluation
(CPE) no later than 60 days
after exceedance and have the
evaluation completed and
submitted to the State no later
than 120 days following exceedance.

Did the system
report the filter number,
the turbidity measurement, the
date(s) on which the exceedance
occurred, and cause(s)
if known?

YES

NO

Did this
exceedance occur at
the same filter in three
consecutive
months?[4]

YES

NO

Was any
individual filter
turbidity measurement > 2.0
NTU for 2 or more consecutive
15-minute readings for
two consecutive
months?[4]

YES

NO

M/R VIOLATION[3]

System is in compliance with individual
filter provisions of the LT1ESWTR

1. Systems with two or fewer filters may conduct continuous monitoring of combined filter effluent in lieu of individual filter effluent turbidity monitoring.
2. Monitoring must be conducted using an approved method in 40 CFR Section 141.74(a). Calibration of turbidimeters must be conducted using procedures specified by the manufacturer.
3. System has an M/R violation until the relevant requirement is completed (such as conducting a filter self-assessment). Public notification is required per Appendix A to Subpart Q of 40 CFR Section 141.
4. For systems with two or fewer filters, combined filter effluent can be substituted for individual filter effluent (see footnote 1). If a filter self-assessment is triggered, the self-assessment must be conducted on both filters.

Figure 2-3. Turbidity Monitoring Requirements for Conventional and Direct Filtration Plants

| Filter #1 | Filter #2 | Filter #3 | Filter #4 |

Record Individual Filter Turbidity (under each filter)

Record Combined Filter Effluent Turbidity every 4 hours

To Clearwell

a) For conventional and direct filtration systems with three or more filters: individual filter turbidity effluent must be recorded at least every15 minutes and combined filter effluent must be recorded at least every 4 hours.

| Filter #1 | Filter #2 | OR | Filter #1 | Filter #2 |

Record Individual Filter Turbidity (under filters #1 and #2)

To Clearwell

Record Combined Filter Effluent Turbidity every 4 Hours

To Clearwell

Record Combined Filter Effluent Turbidity at least every 15 minutes and every 4 hours

b) For systems with two filters: combined filter effluent turbidity or individual filter effluent turbidity must be recorded at least every 15 minutes. In addition, combined filter effluent turbidity must be recorded every 4 hours.

| Filter #1 |

Record Filter Effluent Turbidity every 15 minutes and every 4 hours

c) For systems with one filter: filter effluent turbidity must be recorded at least every 15 minutes and every 4 hours.

40 CFR Sections 141.570-571

Reporting and Recordkeeping

Systems must report the following information to the State for individual filter effluent monitoring:

Description of Information to Report	Frequency
(1) That the system conducted individual filter turbidity monitoring during the month.	By the 10th of the following month.
(2) The filter number(s), corresponding date(s), and the turbidity value(s) which exceeded 1.0 NTU during the month, but only if two consecutive measurements exceeded 1.0 NTU.	By the 10th of the following month.
(3) If a filter self-assessment is required, the date that it was triggered and the date that it was completed.	By the 10th of the following month (or 14 days after the filter self-assessment was triggered only if the filter self-assessment was triggered during the last four days of the month). See Chapter 5 for more information on the filter self-assessment process.
(4) If a CPE is required, that the CPE is required and the date that it was triggered.	By the 10th of the following month.
(5) Copy of the completed CPE report	Within 120 days after the CPE was triggered.

The following chart describes follow-up actions that may be required based on the 15-minute readings:

40 CFR Section 141.563 Required follow-up actions for individual filter effluent turbidity.

If the turbidity of an individual filter (or the turbidity of combined filter effluent (CFE) for systems with 2 filters that monitor CFE in lieu of individual filters) exceeds…	Then the system must...
1.0 NTU for two or more consecutive 15-minute readings in 1 month…	Report to the State by the 10th of the following month and include the filter number(s), corresponding date(s), the turbidity value(s) that exceeded 1.0 NTU, and the cause (if known) for the exceedance(s).
1.0 NTU in two or more consecutive 15-minute readings for 3 consecutive months…	Conduct a filter self-assessment of the filter(s) within 14 days of the day the filter exceeded the 1.0 NTU in two consecutive measurements for the third straight month unless a CPE is required. Systems with two filters that monitor combined filter effluent instead of individual filter effluent must conduct a self-assessment of both filters. The self-assessment must consist of at least the following components: assessment of filter performance; development of a filter profile; identification and prioritization of factors limiting filter performance; assessment of the applicability of corrections; and preparation of a filter self-assessment report.
2.0 NTU in two or more consecutive 15-minute readings for 2 months in a row...	Arrange for a CPE conducted by the State or third party approved by the State not later than 60 days following the day the filter exceeded 2.0 NTU for two consecutive measurements for the second straight month. If a CPE has been completed by the State or a third party approved by the State within the 12 prior months or the system and State are jointly participating in an ongoing Comprehensive Technical Assistance project at the system, a new CPE is not required. If conducted, the CPE must be completed and submitted to the State no later than 120 days following the CPE trigger date.

An exceedance of the individual filter effluent turbidity values <u>does not</u> constitute a treatment technique violation. However, failure to conduct the appropriate follow-up actions <u>does</u> create a treatment technique violation.

40 CFR Section 141.550

2.2 WHAT ARE THE TURBIDITY REQUIREMENTS FOR SLOW SAND AND DIATOMACEOUS EARTH FILTRATION SYSTEMS?

The turbidity standards for slow sand and diatomaceous earth filters did not change from the requirements in the Surface Water Treatment Rule (40 CFR Sections 141.73(b) and (c)). These technologies accomplish 2-log *Cryptosporidium* removal with the turbidity limits set in the Surface Water Treatment Rule.

2.2.1 Combined Filter Effluent Turbidity

Figure 2-5 summarizes the combined filter effluent monitoring requirements for slow sand and diatomaceous earth filtration systems.

Monitoring Requirements

Combined filter effluent turbidity must be measured every 4 hours that the system serves water to the public. The combined filter effluent turbidity for slow sand and diatomaceous earth filtration systems must be less than or equal to 1 NTU for 95 percent of the readings taken each month (unless the State has approved a higher limit as described in 40 CFR Section 141.73(b)(1)) and may at no time exceed 5 NTU (based on turbidity measurements recorded every 4 hours).

For slow sand filtration system of any size, the State may reduce the sampling frequency to once per day if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance.

For diatomaceous earth systems serving 500 or fewer persons, the State may reduce the sampling frequency to once per day if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance.

Reporting and Recordkeeping Requirements

Monthly reports on turbidity from slow sand and diatomaceous earth filtration systems due to the State by the 10th of the following month must contain:

- Total number of combined filter effluent turbidity measurements taken during the month.

- The number and percentage of combined filter effluent turbidity measurements taken during the month which were less than or equal to the system's required 95th percentile limit of 1 NTU.

- The date and value of any combined filter effluent turbidity measurement taken during the month that exceeded 5 NTU.

As required by the Public Notification Rule (40 CFR Section 141.203(b)(3)), if the combined filter effluent exceeds 5 NTU at any time, the system must consult the Primacy Agency within 24 hours.

2.2.2 Individual Filter Effluent Turbidity

Although there are no individual filter effluent turbidity monitoring requirements for slow sand and diatomaceous earth filters in LT1ESWTR, individual filter effluent turbidity monitoring may help identify problems with an individual filter that could be masked when the filtered effluent is blended with filtered effluent from other, properly performing, filters.

While not required of systems using slow sand and diatomaceous earth filtration, it is a good idea to monitor individual filters to identify any individual filter problems that could be masked by monitoring only combined filter effluent.

Figure 2-4. Slow Sand Filter in Idaho

Figure 2-5. Combined Filter Effluent Provisions for Systems Using Slow Sand or Diatomaceous Earth Filtration

Does the system use either surface water or GWUDI, filter, and serve fewer than 10,000 persons?

No → No combined filter effluent requirements under LT1ESWTR

Yes

Does the system use slow sand or diatomaceous earth filtration?

No → System must comply with combined filter effluent provisions for either conventional, direct or alternative filtration.

Yes

All systems using slow sand or diatomaceous earth filtration must comply with combined filter effluent requirements as specified in the SWTR

Did the system monitor combined filter effluent turbidity at 4-hour intervals?[1]

No → M/R Violation[4]

Yes

Was turbidity less than or equal to 1 NTU at least 95% of the measurements taken for the month?

No → TT Violation[4]

Yes

Did turbidity exceed 5 NTU at any time?[2]

Yes → TT Violation[4]

No

Did the system report to the State by the 10th of each month?[3]

Yes → Relevant monthly reporting requirements satisfied.

No → M/R Violation[4]

1. As per the SWTR, 40 CFR Section 141.74 (c)(1), the State may reduce this monitoring frequency to one sample per day for any systems using slow sand filtration or for systems using diatomaceous earth filtration serving 500 or fewer persons if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance.
2. System must consult with the Primacy Agency no later than 24 hours after learning of the violation in accordance with the Public Notification Rule (40 CFR Section 141.203(b)(3)).
3. The total number of turbidity measurements taken during the previous month, the number and percentage of turbidity measurements that were less than or equal to 1 NTU, and date and value of any turbidity measurements exceeding 5 NTU.
4. Public notification is required per Appendix A to Subpart Q of 40 CFR Section 141.

40 CFR Sections 141.551, 141.552, and 141.570

Alternative filtration technologies must provide 2-log *Cryptosporidium* removal, 3-log *Giardia* removal/inactivation, and 4-log virus removal/inactivation.

2.3 WHAT ARE THE TURBIDITY REQUIREMENTS FOR ALTERNATIVE FILTRATION SYSTEMS?

Alternative filtration technologies are defined as technologies other than conventional, direct, slow sand, and diatomaceous earth filtration. Systems using alternative filtration technologies such as cartridges (see Figure 2-6), bags, or membranes must demonstrate (using pilot plant studies or other means) to the State that they meet the following requirements:

- 2-log removal of *Cryptosporidium* oocysts;

- 3-log removal/inactivation of *Giardia lamblia* cysts (referred to as *Giardia*) (also required by 40 CFR Section 141.73(d) in the Surface Water Treatment Rule); and,

- 4-log removal/inactivation of viruses (also required by 40 CFR Section 141.73(d) in the Surface Water Treatment Rule).

A system qualifying as an alternative filtration technology must meet the turbidity limits established by the State by January 1, 2005. Figure 2-7 summarizes the requirements for alternative technologies.

2.3.1 Combined Filter Effluent Turbidity

The State should establish the turbidity limits for the system based on a demonstration that the system is required to conduct under 40 CFR Section 141.552 (see previous paragraph).

Monitoring Requirements

Combined filter effluent turbidity must be measured every 4hours that the system serves water to the public. The combined filter effluent turbidity for alternative filtration systems must be less than or equal to the State-established limit (not to exceed 1 NTU) for 95 percent of the readings taken each month and may at no time exceed the State-established maximum (not to exceed 5 NTU) for any reading. For alternative filtration systems of any size, the State may reduce the sampling frequency to once per day if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance. Systems will want to check with their

State on combined filter effluent requirements since the State may require additional monitoring.

Reporting and Recordkeeping Requirements

Monthly reports on turbidity from alternative filtration systems due to the State by the 10th of the following month must contain:

- Total number of combined filter effluent turbidity measurements taken during the month.

- The number and percentage of combined filter effluent turbidity measurements taken during the month which were less than or equal to the system's required 95th percentile State-established limit (not to exceed 1 NTU).

- The date and value of any combined filter effluent turbidity measurement taken during the month that exceeded the State-established maximum limit (not to exceed 5 NTU).

As required by the Public Notification Rule (40 CFR Section 141.203(b)(3)), if the combined filter effluent exceeds the State-established maximum limit (not to exceed 5 NTU) at any time, the system must consult the Primacy Agency within 24 hours.

2.3.2 Individual Filter Effluent Turbidity

Although there are no individual filter effluent turbidity monitoring requirements for alternative filtration technologies in LT1ESWTR, individual filter effluent turbidity monitoring may help identify problems with an individual filter that could be masked when blended with filtered effluent from properly performing filters.

Figure 2-6. Cartridges Installed at a Small System
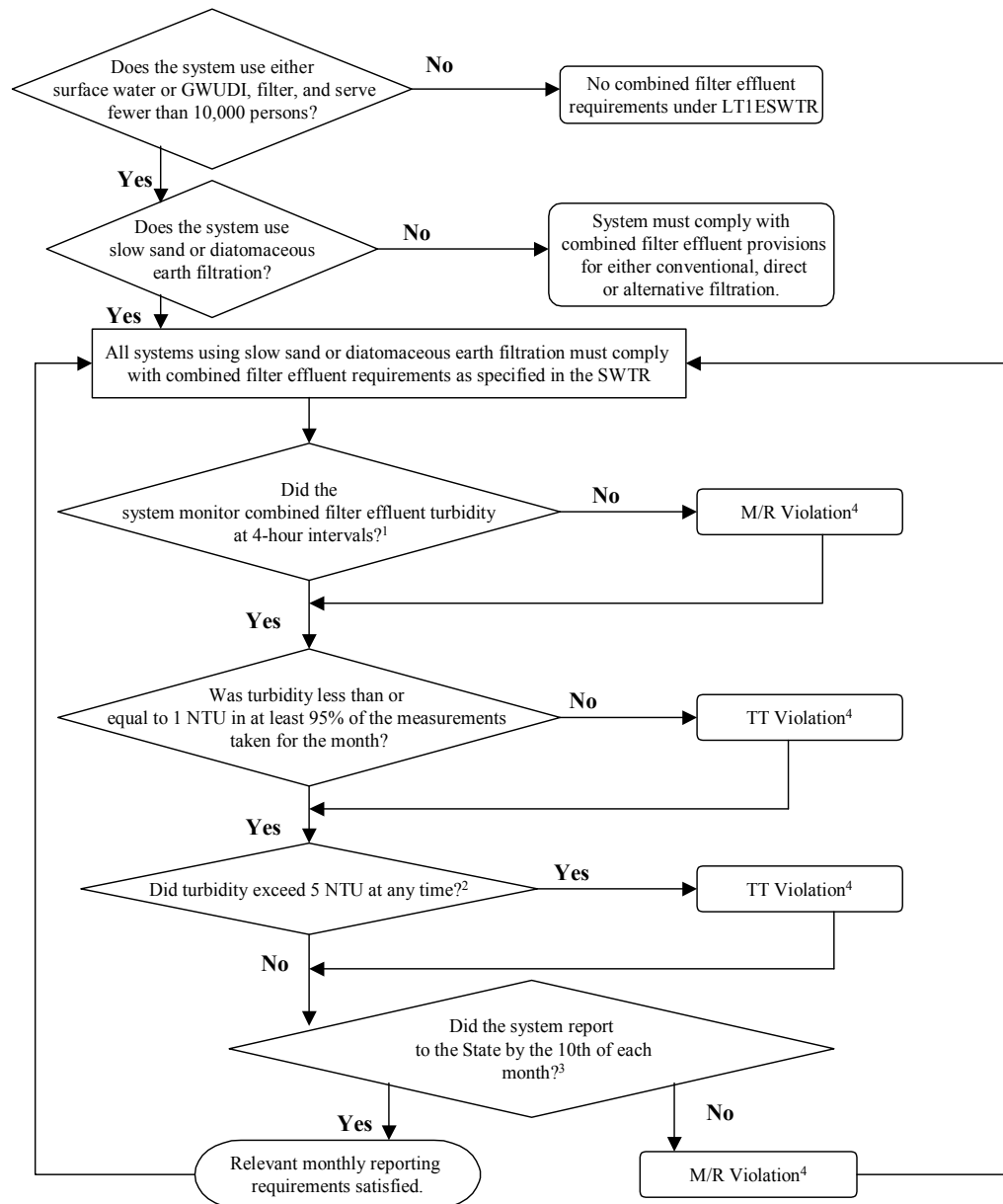
Figure 2-7. Combined Filter Effluent Provisions of the LT1ESWTR
for Systems Using Alternative Filtration Technologies
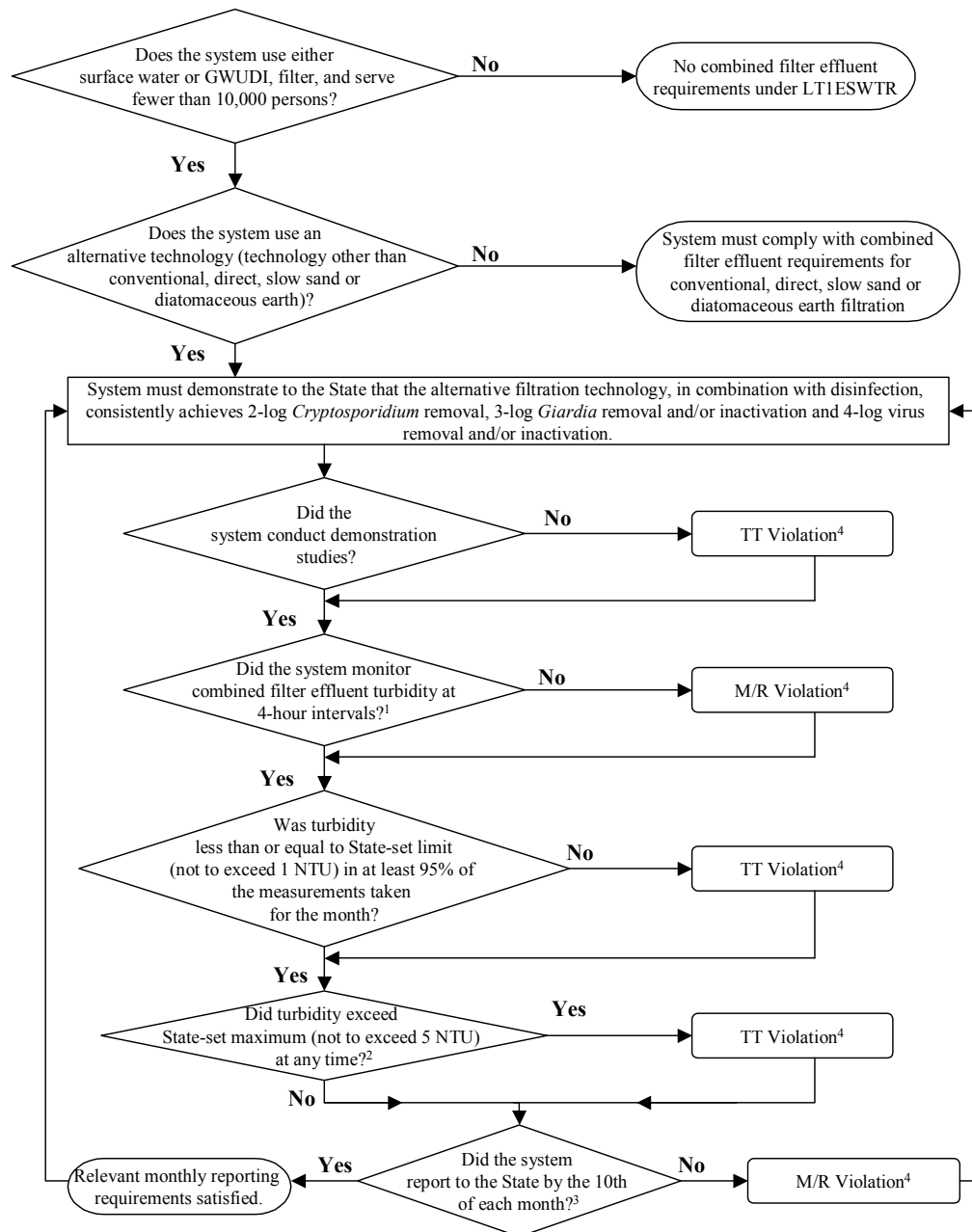
1. As per the SWTR, 40 CFR Section 141.74 (c)(1), the State may reduce this frequency to one sample per day if the State determines that less frequent monitoring is sufficient to indicate effective filtration performance.
2. System must consult the Primacy Agency no later than 24 hours after learning of the violation in accordance with the Public Notification Rule (40 CFR Section 141.203(b)(3)).
3. The total number of turbidity measurements taken during the previous month, the number and percentage of combined filter effluent turbidity measurements that were less than or equal to the State-set limit (not to exceed 1 NTU), and date and value of any combined filter effluent turbidity measurements exceeding the State-set maximum value (not to exceed 5 NTU).
4. Public notification is required per Appendix A to Subpart Q of 40 CFR Section 141.

40 CFR Sections 141.553
and 141.564

Systems that need to
acidify combined filter
effluent turbidity samples
should consult the State on
the proper procedure.

2.4 ARE THERE SPECIAL PROVISIONS FOR SYSTEMS THAT PRACTICE LIME SOFTENING?

Sometimes systems that practice lime softening may experience elevated turbidities due to carryover of lime from the softening processes. If this significantly affects filtered effluent turbidities, systems may acidify representative combined filter effluent turbidity samples prior to analysis using a protocol approved by the State. EPA recommends that acidification protocols lower the pH of samples to less than 8.3. The acid used should be either hydrochloric acid or sulfuric acid of Standard Lab Grade. Care should be taken when handling the acid. EPA recommends that systems maintain documentation regarding the turbidity with and without acidification, pH values (before and after acidification), and the quantity of acid added to a given sample volume.

For individual filter effluent turbidity requirements, systems that practice lime softening may apply to the State for alternative turbidity exceedance values. Systems must be able to demonstrate to the State that the higher turbidity levels are due to lime carryover only, and are not due to degraded filter performance.

3. TURBIDITY SAMPLING METHODS AND TURBIDIMETERS

3.1 INTRODUCTION

All filtered systems must measure the turbidity of combined filter effluent, and conventional and direct filtration systems with more than two filters must also measure individual filter effluent turbidity. Because these measurements are used for reporting and compliance purposes, accurate measurements and the use of approved methods are extremely important. The following sections describe approved methods, analytical issues associated with turbidimeters, and quality assurance and quality control issues. Because turbidity monitoring and reporting are critical to compliance with the LT1ESWTR, spare parts, spare units, and arrangements for rapidly obtaining replacement or on-loan instruments are critical. Turbidity monitoring must be performed as required and only limited allowances are made to accommodate turbidimeter failure.

3.2 APPROVED TURBIDITY METHODS

A system will typically use a continuous monitoring turbidimeter to monitor individual filter effluent, and either a benchtop or a continuous monitoring turbidimeter for combined filter effluent. If a system chooses to use continuous monitoring units for monitoring combined filter effluent, it must validate the continuous measurements for accuracy on a regular basis using a protocol approved by the State.

Figure 3-1. Continuous Monitoring Turbidimeter for Individual Filter Effluent Measurements

40 CFR Section 141.74 (a)(1)

Approved methods for measuring turbidity:

- EPA Method 180.1
- Standard Method 2130B
- Great Lakes Instrument Method 2
- Hach FilterTrak Method 10133

Currently, EPA has approved four methods for measuring turbidity: EPA Method 180.1, Standard Method 2130B, Great Lakes Instrument Method 2, or Hach FilterTrak Method 10133. These methods must be used regardless of whether the turbidimeter is a benchtop model or an on-line unit. Each method is described in *Standard Methods*, 20th Edition (1998) and the *Interim Enhanced Surface Water Treatment Rule Turbidity Provisions Technical Guidance Manual*. Table 3-1 lists commonly used turbidimeters, the corresponding approved EPA method, and turbidimeter capabilities.

Table 3-1. Sampling Methods and Monitoring Capabilities of Some Commonly Used Turbidimeters

Brand[1]	Model-Application	Approved Sampling Method	Monitoring Capability	Form of Output
Hach	2100P – Portable	180.1	N/A	Digital Readout
Hach	2100N IS – Benchtop	180.1	N/A	Digital Readout
LaMotte	2020 – Portable	180.1	N/A	Digital Readout
Hach	1720C - On-line	180.1	15-minute and 4-hour	Digital, Printer Output, and Downloads to a Computer
Hach	1720D - On-line	180.1	15-minute and 4-hour	Digital, Printer Output, and Downloads to a Computer
HF Scientific	Micro 200BW – On-line	180.1	4-hour	Digital, Printer Output, and Downloads to a Computer
HF Scientific	MicroTOL – On-line	180.1	15-minute and 4-hour	Digital, Printer Output, and Downloads to a Computer
Great Lakes	Accu4™ T53/8320 – Low Range- On-line	GLI2	15-minute and 4-hour	Digital, Printer Output, and Downloads to a Computer

[1] The listed brands and models are just a few of the units available to measure turbidity that EPA is aware of. Please let us know if there are other manufacturers which were not represented. Systems may use any turbidimeter provided it can be used with an EPA-approved method.

Note: EPA does not endorse any particular manufacturer or product model.

3.3 SAMPLE COLLECTION

Proper sample collection is important to ensure the sample is representative of the water being analyzed. For both on-line and grab sampling, the length of the sample piping or tubing from the sampling location to the point where the sample is drawn should be minimized. Long sample lines can lead to problems with biological fouling and scaling which can impact turbidity values. It is best to limit the length of sample lines to 10 feet or less. Long sample lines can also cause confusion due to the lag time as the sample travels through the piping. The longer the lag time, the more difficult it is to correlate turbidity fluctuations to actual process changes that might be occurring. For on-line units, lengthy sample runs can delay instrument response time and may cause changes in sample quality (i.e., settling of particulate matter, increased opportunity for biological growth).

You should install sample lines so they are easy to disconnect and clean.

Sample lines should be installed in a way that makes them easy to disconnect and clean, because they sometimes plug. Care should be taken to keep these lines open and clean. Rotameters can be installed on the influent piping or on tubing to the sample site to ensure good flow. The tubing or piping used for the sample line should be made of PVC, copper, PTFE (teflon), or a material recommended by the turbidimeter manufacturer.

Continuous flow through the sample line is preferred to prevent sediment build-up in the sample line.

You should carefully consider the location of the sample tap. The tap should provide a representative sample of the water being monitored. If an individual filter is being monitored, locate the sample tap as close to the filter as possible. The individual filter effluent tap should also be installed before the filter-to-waste line. This way, operators can monitor filter effluent turbidity during the filter-to-waste process so that filters are not placed into service before their turbidity goal is achieved. Sample taps or tubing/piping taps should be located close to the centerline of individual filter effluent or combined filter effluent pipes, not on the top or bottom of the pipe where the turbidity of the water will not be accurately represented. Samples taken from the bottom will often contain sediment, while samples from the top may contain a greater number of air bubbles. Ideally, sample taps should extend into the center of the flow channel and should be angled into the water flow between 0 and 45 degrees. Sample taps should also be located away from items that disturb flow such as fittings, bends, meters, or pump discharges (Logsdon et al., 2000).

Figure 3-2 illustrates two sample tap locations that could be used for grab samples. If the tap located on the sample line is used, then the line should be flushed to remove sediment prior to taking a sample. The tap located on the on-line turbidimeter could also be used and would typically not require flushing prior to taking a grab sample.
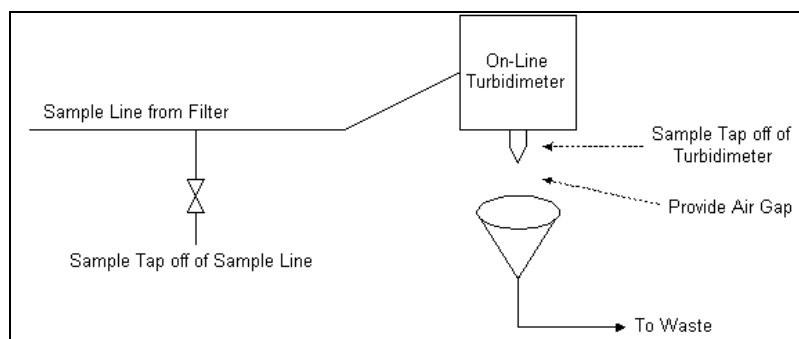
Figure 3-2. Sample Locations for Removing Grab Samples

You should avoid using clear tubing for the sample line because clear pipe is prone to algae growth.

In selecting sample tubing or piping, the required sample flow rate and pressure should be considered. Sample lines of insufficient diameter may not provide adequate flow to the instrument and may be prone to clogging. Excessively large diameter sample lines will delay the instrument response and may permit settling of particulate matter. Line flushing valves and ports may be necessary depending on the water being sampled.

Some States require that a certified operator take all turbidity samples. Check with your State on this requirement.

3.3.1 Timeliness of Sample Analysis

You should analyze turbidity samples as quickly as possible to avoid issues related to temperature changes and settling.

Samples analyzed by a benchtop turbidimeter should be analyzed as quickly as possible after being taken to prevent changes in particle characteristics due to temperature changes and settling. Temperature changes can affect particles by changing their behavior, by causing reactions that result in the creation of new particles, and by reducing the number of particles through solubilization. Operators are encouraged to draw samples only when turbidimeters are ready to be operated. Operators should not draw a sample and allow it to sit while the instrument warms up or is being readied.

Samples entering the turbidimeters should be at the same temperature as the process flow samples. Changes in temperature can cause precipitation or cause compounds to become soluble and affect readings.

3.3.2 Sampling Strategy and Procedures

The procedure for conducting sampling should be laid out clearly and concisely in Standard Operating Procedures (SOPs) (discussed in Section 3.8.3) and should be incorporated in the plant's operation and maintenance plan. It should include information such as sampling location and frequency, collection methods, sample handling, and any necessary logistical considerations or safety precautions. Adherence to proper techniques is important to minimizing the effects of instrument variables and other interferences (Sadar, 1996). Measurements will likely be more accurate, precise, and repeatable if operators follow and incorporate the techniques listed in this section.

All turbidimeter manufacturers emphasize proper techniques and include detailed instructions in their literature. Water treatment plant operators responsible for conducting turbidity measurements are urged to review these instructions and incorporate them into their SOPs. Specific instructions for securing samples and measuring turbidity will differ for the various instrument manufacturers and models, but there are certain universally accepted techniques that should be used when conducting measurements. The following paragraphs highlight some of these techniques.

3.3.3 Handling of Benchtop Turbidimeter Sample Cells

Sample cells used in benchtop turbidimeters should be handled with absolute care to avoid contamination or damage, such as marks and scratches, which might change the optical characteristics of the glass. Scratches, fingerprints, and water droplets on the sample cell or inside the light chamber can cause stray light interference leading to inaccurate results. For this reason, it is important to visually inspect the sample cell every time a measurement is made and verify the cell is clean and free of scratches. If there is a question as to whether a sample cell is too scratched or stained, it should be discarded.

Sampling Standard Operating Procedures should include:

- Sample location and frequency

- Collection methods

- Sample handling

- Necessary logistical considerations

- Safety precautions

You should handle sample cells with care and check for cleanliness and scratches prior to use.

Personal protective clothing should be worn when handling acid.

You should not add water to acid when preparing a dilute acid solution. The acid should be added to the water.

Cells should be cleaned by washing with laboratory soap, inside and out, followed by multiple rinses with distilled or deionized water and air-drying. Cells can also be acid washed periodically. To acid wash, first wash the cell as just described and rinse with a 1:1 hydrochloric acid solution or 1:1 nitric acid solution (i.e., one part acid to one part distilled or deionized water). If required to prepare the acid rinse solution, you should use extreme caution. For this procedure, the acid should be added to the water. You should not add water to acid. Then rinse the sample cell with distilled or deionized water and let air dry. Chromic acid may also be used to remove organic deposits, but you should make sure the cell is rinsed thoroughly to remove traces of chromium (Sadar, 1996). The frequency of cleaning depends on the frequency of use of the sample cell and will vary from plant to plant.

You may want to consider coating the sample cell exterior with a special silicone oil to fill small scratches and mask the imperfections in the glass. Since the silicone oil required for this application should have the same refractive characteristics as glass, it is recommended that the oil be obtained from the instrument manufacturer. Care should be taken not to apply excessive oil that could attract dirt or contaminate the sample chamber in the instrument. Once the oil has been applied to the cell, the excess oil should be removed with a lint-free cloth. The result should be a sample cell surface with a dry appearance, but with all imperfections filled with oil. Sample cells should be handled at the top of the cell or by the cap to avoid fingerprints or smudges. After a cell has been filled with a sample and capped, the outside surface should be wiped with a clean, lint-free absorbent cloth until it is dry.

Before placing the clean sample cell in a turbidimeter, gently swirl the sample cell to reduce particle settling. You should verify that there are no visible bubbles in the sample before measuring turbidity.

The cells should be stored in an inverted position on clean surfaces to reduce contamination by dirt and dust or stored capped and filled with low-turbidity water (e.g., tap, distilled, or deionized water). The cells should be replaced after their useful life as recommended by the manufacturer or if damaged.

3.3.4 Orientation and Matching of Benchtop Turbidimeter Sample Cells

Because imperfections in the sample cell glass can influence light scattering, the cell should be inserted in the benchtop turbidimeter with the same orientation each time it is used.

Matched sample cells should be used to minimize the effects of optical variation among cells. If possible, it is best to use a single sample cell for all measurements to minimize the variability due to cell-to-cell imperfections. Once the orientation of a cell has been established, the operator should always use the same orientation when placing the sample cell into the instrument. Suggested techniques for indexing and matching cells are described below.

To index cells, follow steps 1 and 2; to match cells, follow steps 1-3:

- Step 1. Pour ultra-pure dilution or deionized water (may be available from the manufacturer or a laboratory) into a sample cell (there will be several cells if the operator is performing matching) that has been cleaned according to the techniques described previously in this section.

- Step 2. Place the sample cell in the turbidimeter. Rotate the cell within the instrument until the display reads the lowest value. Record the reading. Using a marker or pen, place a mark on the top of the neck of the sample cell. Do not put the mark on the cap. Place a corresponding mark on the turbidimeter (or select a mark on the turbidimeter that is in a fixed position and can be used to align the sample cell each time). Use these marks to align sample cells each time a measurement is made.

- Step 3. Select another sample cell, place it in the turbidimeter, and rotate the cell slightly until the reading matches that of the first sample cell (within 0.01 NTU). Using a marker or pen, place a mark on the top of the neck of the sample cell. If unable to match the readings, select a different sample cell. Repeat the process until the appropriate number of cells have been matched.

At the Philadelphia Water Department, new cells are indexed and are not allowed to vary by more than 0.01 NTU. Philadelphia reports that as many as one quarter of the sample cells are never used due to imperfections (Burlingame, 1998).

You should allow the benchtop turbidimeter to stabilize prior to recording a reading.

If the evaluation for matching cells determines that a cell is corrupted, the cell should be discarded. Systems should consider conducting this evaluation weekly.

3.3.5 Degassing the Sample

Water samples almost always contain substantial amounts of air bubbles that can be released during turbidity measurements. Bubbles are generated during the filling of a sample container, occur due to released dissolved oxygen at increased water temperature, or are due to chemical or biological processes. Samples collected from a pressurized line may also release dissolved oxygen and generate bubbles. Bubbles within a sample act much like particles and can scatter light and cause an incorrect measurement. Some on-line turbidimeters have internal bubble traps and degassing capabilities to reduce the amount of bubbles.

There are several options for removing bubbles from a sample (a process called degassing) to reduce the effect they have on measurements made using a benchtop turbidimeter. These include application of a partial vacuum, addition of a surfactant, and use of an ultrasonic bath (Hach et al., 1990). These degassing methods can be difficult to use, and turbidity measurements may be affected if not done correctly.

One method for degassing samples is to apply a partial vacuum to the sample. A partial vacuum can be created using a syringe or a vacuum pump. A 50-cubic-centimeter plastic syringe fitted with a small rubber stopper is the easiest, most cost-effective method. After the sample cell is filled with the appropriate volume of sample, the stopper is inserted into the top of the cell. As the syringe plunger is withdrawn, pressure within the cell drops and gas bubbles escape. Some instrument manufacturers and suppliers provide pre-made vacuum kits that include syringes for degassing samples.

Another method is the addition of a surfactant. The surfactant lowers the surface tension of the water and causes the air bubbles to be released. Surfactants are recommended for high turbidity water, such as raw water, and the surfactant used should be supplied by the instrument manufacturer because of the high variability of surfactants.

Bubbles can act much like particles and scatter light resulting in a falsely higher turbidity reading.

Some degassing options may include:

- Creating a partial vacuum in the sample line

- Adding a surfactant

- Using an ultrasonic bath

The third method is to use an ultrasonic bath. The ultrasonic bath is recommended when numerous air bubbles are present or if the sample is viscous. The ultrasonic bath uses high frequency sound waves that cause the air bubbles to collapse.

Using a partial vacuum or ultrasonic bath should be approached with caution. Both of these techniques can result in more air bubbles if not used properly (Hach et al., 1990).

3.4 INSTALLATION

Although turbidimeters are built to be durable, they should be stored and operated in a safe and protected environment. Moisture and dust can accumulate inside turbidimeters that are not adequately protected and may affect the functioning of the turbidimeter. Humidity should also be controlled to prevent condensation inside the instrument. Turbidimeters should not be located where they will be exposed to corrosive chemicals or fumes because chemicals such as chlorine and acids can ruin instrumentation. They should be protected from direct sunlight, extreme temperatures, and rapid temperature fluctuations. Finally, turbidimeters should be located in a temperature-controlled environment at a consistent temperature between 0° C (32° F) and 40° C (104° F).

On-line turbidimeters should be installed in accordance with manufacturer instructions. The goal of proper installation is to ensure correct operation and easy access for routine maintenance and calibration. These units should also be firmly mounted to avoid vibrations that may interfere with the accuracy of the turbidity measurements.

If pumping is necessary, you should select a pump that does not contact the water or excessively agitate it.

Sample pumps can affect the turbidity measurements of on-line units. It is good practice to have on-line turbidimeters near sample collection points to avoid having to pump the sample across the plant. A good sample tap location and plumbing arrangement will minimize potential bubble formation. Most on-line turbidimeters have the capability to eliminate minor bubble interference through baffles or degassing chambers, but if the problem is severe, the turbidity measurements may be affected.

For on-line turbidimeters, the drain should provide easy access for flow verification and collection of calibration and verification samples. Flow rate and calibration verification samples are important in establishing data validity. Therefore,

hard piping the turbidimeter drain without an airgap is not recommended.

3.5 BENCHTOP TURBIDIMETERS

Benchtop units are used exclusively for grab samples. They have glass sample cells (or "cuvettes") for holding the sample. Measurements with benchtop units require strict adherence to the manufacturer's sampling procedure to reduce errors from dirt, scratches, condensation on glassware, air bubbles in the sample, and particle settling. Operators should read and be fully familiar with the operation manuals for all benchtop turbidimeters used in the plant. Many maintenance and operational issues are specific to the turbidimeter make and model, and instruments are usually shipped with a thorough user's manual.

Turbidimeters should be checked after lightning storms or any time that the power has gone out.

Figure 3-3. A Benchtop Turbidimeter.

Preventive maintenance can extend the life of any type of turbidimeter.

Benchtop turbidimeters should be connected to an uninterruptible power supply or a constant voltage. Loss of power or voltage fluctuations can damage the turbidimeter and result in faulty readings. Generally, the instrument should be left on at all times (unless otherwise specified in the user's manual), otherwise the instrument may require a warm-up period before sample analysis. The need for an uninterruptible power supply and leaving the instrument on at all times will depend on the site-specific application of the benchtop turbidimeter (e.g., is the benchtop turbidimeter used for measuring combined filter effluent on a regular basis, backup, or to measure raw water turbidity?).

3.5.1 Preventive Maintenance

Preventive maintenance should be conducted on all benchtop turbidimeters. Preventive maintenance includes procedures that are regularly scheduled, even when there are no apparent problems with the instrument. Systems should follow the preventive maintenance schedule recommended by the instrument manufacturer. Manufacturers' procedures identify the schedule for servicing critical items to minimize downtime of the instrument.

You should not touch the optical components with bare hands. (Soft cotton gloves are recommended.)

The preventive maintenance program should include:

- Regular battery checks.

- Maintenance of a sufficient stock of spare instruments, spare parts, and supplies.

- Regular (such as monthly or quarterly) inspection of the cleanliness of bulbs and lenses. Remember when cleaning the lenses, light sources, and other instrument components, you should use appropriate materials recommended by the manufacturer to avoid scratches and dust accumulation. You should recalibrate the instrument after the cleaning procedure is complete.

- Annual replacement of incandescent turbidimeter lamps. You should replace lamps more frequently if recommended by the manufacturer. You should recalibrate the instrument whenever optical components (e.g., lamp, lens, photodetector) of the turbidimeter are replaced.

- Recording of calibrations, bulb replacements, and any other maintenance in a maintenance log to ensure consistency in measurements and performance.

Good working turbidimeter = accurate and reliable turbidimeter measurements.

In addition, systems may consider annual servicing of benchtop turbidimeters by a third party, preferably a manufacturer's representative or technical assistance provider. However, servicing by a third party may not always be desirable or affordable.

Benchtop turbidimeters, like most instruments, have a limited service life. Various elements in the instrument can deteriorate over time and with repeated use. Daily usage can result in wear on electronics due to movement and temperature.

Microprocessor-based electronics are also prone to memory loss during power supply fluctuations. Manufacturer's service personnel can often provide insight on instrument life and can make recommendations for specific maintenance items. Most manufacturers have a technical support hotline and can provide expert advice about turbidimeters. Since turbidimeters have become an integral part of water treatment plant operation and reporting, the system should maintain instruments and budget for replacements.

3.5.2 Corrective Maintenance

Keeping a spare benchtop turbidimeter on hand at all times could save time and money in the long run.

Corrective maintenance should be carried out according to the manufacturer's instructions. You should not make repairs to the benchtop turbidimeter unless they are specified in the instruction manual. Even if a repair can be made in-house, consider sending the unit back to the manufacturer for repair. The warranty may become void if repair is performed in-house. You should keep track of maintenance and repair on a log sheet for each unit. Even if a unit is sent away for repairs, required turbidity monitoring must still be performed and recorded. Therefore, systems should consider keeping a spare turbidimeter on hand.

Always recalibrate the instrument after any significant maintenance or cleaning procedure, but only as directed by the manufacturer.

Any maintenance that is done should be documented and the record kept in a designated place (such as next to the instrument or in an operation and maintenance manual). Maintenance procedures and schedules for equipment used should always be available to the staff that conducts the maintenance. A sample maintenance form for recording maintenance milestones for bench-top turbidimeters is provided in Table 3-2. Blank sample maintenance forms can be found in Appendix B.

Table 3-2. Sample Maintenance Form

Instrument: Benchtop in Lab					
Date	Verification	Acceptable/ Unacceptable	Maintenance Performed	Initials	Comments
1/8/05	✓	Acceptable	None	S.S.	
1/16/05	✓	Unacceptable	Changed Bulb	S.S.	Bulb was bad
1/23/05	✓	Acceptable	Replaced sample cell	T.T.	

3.6 ON-LINE TURBIDIMETERS

On-line turbidimeters are process instruments that continuously sample a side stream split-off from the treatment process. The sample flows through the on-line instrument for measurement and then is wasted to a drain or recycled through the treatment process.

The flow rate through on-line turbidimeters should be set in accordance with manufacturer specifications. The sample flow should be as constant as possible without variations due to pressure changes or surges. Installation of a flow control device such as a rotameter on the sample line can control fluctuations.

For further information regarding on-line turbidimeter requirements and recommendations, refer to the American Society for Testing and Materials (ASTM) Standard D6698-01.

To the extent possible, turbidimeter samples should be obtained directly from the process flow and not pumped to a remote instrument location. Pumped samples can be non-representative of the process flow due to changes in the character of particles caused by the pump or the addition of bubbles due to rapid pressure changes. If pumping is required, the use of peristaltic pumps is desirable, because they have the least impact on particles in the sample.

Figure 3-4. The Hach 1720C On-Line Turbidimeter

3.6.1 Preventive Maintenance

Preventive maintenance should be conducted on all instruments. Preventive maintenance includes procedures that are regularly scheduled, even when there are no apparent problems with the instrument. Systems should follow the preventive maintenance schedule recommended by the instrument manufacturer. Manufacturers' procedures identify the schedule for servicing critical items to minimize downtime of the measurement system.

The preventive maintenance program should include:

- Regular battery checks.

- Maintenance of a sufficient stock of spare turbidimeters, spare parts, and supplies.

- Routine inspections of turbidimeters and sample lines for scaling, algae, and cleanliness.

- Recalibration of the instrument whenever maintenance is performed.

- Recording of any maintenance, calibration, or verification on a form or in a log book to ensure consistency in measurements and performance.

Systems may consider annual servicing of turbidimeters by a third party, preferably a manufacturer's representative or

Preventive maintenance can save time and money in the long run.

Cracks or biological growth in the sample line can affect turbidity readings.

technical assistance provider. However, servicing by a third party may not always be desirable or affordable.

A regular cleaning schedule ensures proper operation of on-line turbidimeters. On-line turbidimeters should be cleaned according to the manufacturer's instructions. A weekly inspection is recommended, but the frequency may vary depending on instrument location and water quality. A turbidimeter that measures warm or turbid raw water samples, or that is mounted in a dusty area, may need more frequent cleaning. Items to inspect and clean include, but are not limited to, lenses, light sources, sample reservoirs, air bubble traps, and sample lines. Clean lenses, light sources, and other glassware with appropriate materials to avoid scratches and dust accumulation. During maintenance, care needs to be taken not to touch the surface of any bulbs or detectors without proper covering on the fingers. Soft, clean cotton gloves should be worn when changing bulbs or detectors. The instrument should be recalibrated after any significant maintenance or cleaning. Also, the condition of the sample line should be checked for cracks or biological growth. When cleaning the sample line, you should make sure the line is flushed thoroughly before reconnecting it to the turbidimeter.

3.6.2 Corrective Maintenance

When calling a technical support hotline, it is helpful to have available the model number of the turbidimeter and information on process conditions that may be adversely affecting the instrument.

On-line turbidimeters, like most instruments, have a limited useful service life. Various elements in the instrument can deteriorate over time and with repeated use. Daily usage can result in wear on electronics due to movement and temperature. Microprocessor-based electronics are also prone to memory loss during power supply fluctuations. Many on-line units with unsealed sensor electronics are vulnerable to damage by outside contamination and splashing. Service personnel can often provide insight on instrument life and can make recommendations for specific maintenance items. Most manufacturers have a technical support hotline where expert advice about on-line turbidimeters can be obtained. Since turbidimeters have become an integral part of water treatment plant operation and reporting, it is important to maintain instruments and budget for replacements.

Any maintenance that is done should be documented.

Calibration – A procedure that adjusts or checks the accuracy of an instrument (turbidimeter) by comparison with a standard (primary standard) or reference.
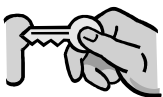
Verification – A procedure using secondary standards to verify the calibration of an instrument (turbidimeter).

Consult the turbidimeter owner's manual to determine proper calibration procedures associated with the instrument.

3.7 CALIBRATION AND VERIFICATION OF TURBIDIMETERS

Calibration is an essential part of accurate turbidity measurement. *Calibration* refers to the process of programming a turbidimeter to read the turbidity of one or more solutions of known turbidity value (called primary standards). Once calibrated, the unit should provide accurate measurement of the turbidity of a water sample.

Secondary standards are used for *verification*. If verification indicates significant deviation from the secondary standard stock solution (for example, greater than ±10 percent for 1 NTU standard solutions), you should thoroughly clean the instrument and recalibrate it using a primary standard. If problems persist, the manufacturer should be contacted.

Turbidimeters, like all instrumentation, need to be calibrated periodically to ensure that they are working properly and providing true and accurate readings.

Calibration procedures for one turbidimeter may not be the same for another turbidimeter. Therefore, you should make sure the procedures you are using are for the turbidimeter's particular:

- Manufacturer;
- Model name and/or number;
- Parameters to be calibrated;
- Range to be calibrated; and,
- Acceptance criteria.

After calibration, you should verify instrument performance with a secondary standard or by comparison with another properly calibrated instrument. If the instrument has internal electronic diagnostics designed to assist in determining proper calibration, the operator should use these tools to verify proper calibration and operation.

If verification indicates significant deviation from the secondary standard (±10 percent for 1 NTU standard solutions), the instrument should be thoroughly cleaned and recalibrated using a primary standard. If problems persist, the manufacturer should be contacted. Regardless of verification
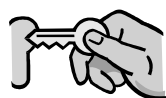
results, turbidimeters should be calibrated with primary standards **at least quarterly** or more frequently if specified by the manufacturer.

You should not calibrate on-line instruments by comparison with a bench-top turbidimeter. It has been determined that this procedure is likely to introduce unacceptable levels of error into the calibration. However, verification by comparison is acceptable.

3.7.1 Calibration and Verification Standards

A known standard must be used to conduct a primary calibration. Standards are materials with a known value which, when placed in the instrument, should be used to adjust the instrument to read the known value.

There are a variety of standards on the market today, which are used to calibrate turbidimeters. They are most often characterized as primary, secondary, or alternative standards. *Standard Methods*, 20th Edition (1998), describes a primary standard as one that is prepared by the user from traceable raw materials, using precise methodologies and under controlled environmental conditions. Secondary standards are defined as standards a manufacturer (or an independent testing organization) has certified to give instrument results equivalent (within certain limits) to results obtained when an instrument is calibrated with a primary standard.

EPA recognizes the following three standards for approved use in the primary calibration of turbidimeters:

- Formazin (user prepared and commercially produced);

- AMCO-AEPA-1® Microspheres; and,

- STABLCAL® (Stabilized Formazin).

In addition, EPA recognizes secondary standards for use in monitoring the day-to-day accuracy of turbidimeters by checking the calibration. This check is used to determine if calibration with a primary standard is necessary. Secondary standards are used to check or verify whether an instrument produces measurements within acceptable limits around a nominal value (typically $\pm$ 10 percent). Examples of secondary standards are:

You should realize that some instruments have been designed and calibrated on specific primary standard(s). For optimal results, users should contact the manufacturer of the instrument to determine the recommended primary standard to be used for calibration.

3. Turbidity Sampling Methods and Turbidimeters

Ensure the standards used for calibration and verification are in the appropriate ranges.

- GELEX®;

- Glass/ceramic cubes; and,

- Manufacturer-provided instrument-specific secondary standards.

Standard Methods, 20th Edition (1998), and EPA differ in their definitions of each of these standards. The need to reconcile the definitions and differences between primary and secondary standards will be a continuing issue. It has been recognized that the standards need to be unbiased, easy to use, safe, reproducible, and available for a range of turbidities. Future efforts of the Agency, in concert with other organizations and manufacturers, will focus on ensuring the most appropriate, variation-free, and technologically feasible standards are available and used for calibration of turbidimeters. Tables 3-3 and 3-4 contain a list of commonly used turbidimeters and the calibration standard.

Table 3-3. Some Commonly Used Primary Calibration Standards and Turbidimeters

Brand[1]	Model – Type	Primary Calibration Standard Formula[2]
Hach	2100P – Portable	Formazin or StableCal®
Hach	2100N IS – Benchtop	Formazin or StableCal®
LaMotte	2020 – Portable	AMCO™ 2020 Turbidity Standards or Formazin
Hach	1720C – On-line	Formazin or StableCal®
Hach	1720D – On-line	Formazin or StableCal®
HF Scientific	Micro 200 – On-line	Formazin
HF Scientific	Micro TOL – On-line	Formazin
Great Lakes Instruments International	Accu4 T53/8320 – Low Range – On-line	Formazin – Primary Calibration not Required[3]

[1] The listed turbidimeters are just a few of the units available to measure turbidity that EPA is aware of. Please let us know if there are other manufacturers which were not represented. Other turbidimeters can be used provided they can be used with an EPA approved method.

[2] Always consult the manufacturer for proper calibration formulas. Manufacturers typically supply these formulas.

[3] Practical lifetime calibration is provided by GLI's patented 4-beam ratiometric measurement method: US EPA approved GLI Method 2. After performing initial calibration, only periodic verification of calibration is required.

Note: EPA does not endorse any particular manufacturer or product model.

Table 3-4. Some Commonly Used Secondary Calibration Standards and Turbidimeters

Brand[1]	Model – Type	Secondary Calibration Standard Formula[2]
Hach	2100P – Portable	Gelex®
Hach	2100N IS – Benchtop	Gelex®
LaMotte	2020 - Portable	No secondary standards
Hach	1720C – On-line	ICE-PIC™ Calibration Module
Hach	1720D – On-line	ICE-PIC™ Calibration Module
HF Scientific	Micro 200 – On-line	HF Scientific Calibration Set
HF Scientific	Micro TOL – On-line	HF Scientific Calibration Set
Great Lakes Instruments International	Accu4 T53/8320 – Low Range – On-line	Cal-Cube™

[1] The listed turbidimeters are just a few of the units available to measure turbidity that EPA is aware of. Please let us know if there are other manufacturers which were not represented. Other turbidimeters can be used provided they can be used with an EPA approved method.

[2] Always consult the manufacturer for proper calibration formulas. Manufacturers typically supply these formulas.

Note: EPA does not endorse any particular manufacturer or product model.

3.7.2 Conducting the Calibration

Most turbidimeters are calibrated before leaving the factory. As described previously, turbidimeters, like most instrumentation, tend to lose accuracy over time due to a variety of factors, making periodic calibration very important to maintain accurate measurements. The most important point to remember is:

Calibration must be conducted using procedures specified by the manufacturer.

Manufacturers differ in the steps to conduct a calibration, but the following points should be considered when calibrating a turbidimeter:

Suggested tips for calibration:

✓ Use current and correct standards

✓ Use clean cells

✓ Record all calibrations

✓ Perform calibration consistently

✓ Check with the turbidimeter manufacturer or State with questions

- **Standards should be checked to ensure they have not expired.** You should not pour a standard back into its original container.

- Secondary standards may be different from the system's primary standard.

- Care should be taken when preparing Formazin or another standard. If a spill occurs, you should clean it up immediately according to the Material Safety Data Sheets (MSDSs) provided with the chemicals.

- You should inspect the cell for scratches and chips prior to pouring the solution into the cell (specific to benchtop and portable units).

- You should make sure the cell is lined up properly according to the indexing (specific to benchtop and portable units). You should be sure not to scratch the tube when inserting it, and you should ensure that the cell is free of dust, smudges, and scratches.

- When obtaining the reading, you should write the value legibly onto a form similar to the one found in Table 3-5. (Blank forms are available in Appendix B.) A separate calibration checklist should be used for each instrument. You should make sure to record the date of the calibration, the individual conducting the calibration, the value, and any peculiar situations or deviations from normal calibration procedures (e.g., switch to a new lot of Formazin, switch in standards, use of a new cell). These measurements will indicate whether the performance of a turbidimeter is in

Due to the importance of accurate and reliable turbidity measurements, adequately training new operators on calibration and verification procedures is very important.

question. For example, if for 6 months a turbidimeter reads approximately 20.152 when calibrated using polystyrene beads and one morning it reads 25.768, this change could be an indication that the bulb in the turbidimeter has a problem. Conversely, if the standard in use was switched that morning, the resulting change might be due to the change in standards.

- You should conduct the calibration the same way each time. Variations in how the calibration is conducted could yield inaccurate measurements.

- Individuals should be trained on the calibration procedures. Systems should create SOPs to be read, learned, and followed by operators at the plant.

- The turbidimeter manufacturer is the best resource for specific calibration techniques applicable to the turbidimeter.

- The State may have more information about proper calibration standards and requirements.

Table 3-5. Example Calibration Checklist

CALIBRATION CHECKLIST

Instrument: Turbidimeter #3

Date	Initials	Recorded Value (NTU)	Value of Standard (NTU)	Comments
3/28/05	AZ	20.127	20.000	
6/29/05	AZ	20.183	20.000	
9/30/05	AZ	20.156	20.000	
12/27/05	AZ	19.980	20.000	
3/27/06	AZ	20.062	20.000	new lot of formazin used
6/23/06	AZ	20.168	20.000	

You should calibrate turbidimeters at least quarterly, or more frequently if specified by the manufacturer.

3.7.3 Calibration and Verification Frequency and Procedures

Calibration Frequency and Procedures

Both benchtop and on-line turbidimeters should be thoroughly cleaned with the appropriate cleaning solution and calibrated with primary standards ***at least quarterly*** (or more frequently if specified by the manufacturer), even if there do not appear to be any problems with the instrument. Calibration schedules should be kept in the plant's operation and maintenance manual or other designated place. The State or primacy agency may have more information about the appropriate protocol. Specific calibration procedures should be developed for each individual instrument location. Suggested guidelines include:

- Selecting a frequency for full re-calibration of instruments with primary standards.

- Performing primary calibration on all turbidimeters at least quarterly.

- Performing primary calibration on any turbidimeter that has drifted " 10 percent from the value assigned to the standard used for secondary calibration.

- Identifying and scheduling in advance the dates for full turbidimeter calibration and marking them on the plant calendar or work scheduling chart.

You should use fresh standards when performing calibrations.

- Making preparations and maintaining adequate supplies to prevent delays in the calibration schedule. It is important to keep an appropriate stock of standards. Due to the limited shelf life of various standards, the age of the stored standards should be monitored so they can be replaced or reformulated as needed.

- If you have several operators, assigning calibration duties to a select group of individuals, and making it one of their standard activities. All appropriate individuals/operators should be trained in conducting a calibration in the event that one of the regular individuals is not available.

- Creating an SOP for conducting a calibration and posting it near the turbidimeter.

Table 3-6 can be used as a guide for scheduling calibration of on-line turbidimeters.

Verification Frequency and Procedures

EPA recommends that systems using on-line turbidimeters for combined filter effluent monitoring verify the calibration on a weekly basis. Less frequent verification may be appropriate for turbidimeters monitoring individual filter effluent turbidity because on-line combined filter effluent turbidimeters that monitor the collective individual filter effluent turbidities are verified more frequently. Still, EPA recommends verification be conducted for individual filters at least once per month. Suggested guidelines include:

- Selecting a frequency for checking (verifying) instrument calibration with secondary standards.

- Making preparations and maintaining adequate supplies to prevent delays in the verification schedule.

It is important to keep an appropriate stock of standards. Due to the limited shelf life of various standards, the age of the stored standards should be monitored so they can be replaced or reformulated as needed.

- If you have several operators, assigning verification duties to a select group of individuals, and making it one of their standard activities. All appropriate individuals/operators should be trained in conducting a verification in the event that one of the regular individuals is not available.

- Creating an SOP for conducting a verification and posting it near the turbidimeter.

Table 3-6 can be used as a guide for scheduling verification of on-line turbidimeters.

Table 3-6. Suggested On-line Turbidimeter Calibration and Verification Schedule

Monitoring Location	Procedure	Recommended Frequency
All Locations	Calibration	Quarterly[*]
Individual Filter Effluent	Verification	Monthly or Weekly
Combined Filter Effluent	Verification	Weekly

* If the manufacturer specifies more frequent calibration, 40 CFR Section 141.560(b) requires you to do so.

QA/QC = Quality Assurance/Quality Control

3.8 QUALITY ASSURANCE / QUALITY CONTROL

Systems may want to establish plans to ensure that measurements are being made accurately and consistently. Using proper techniques and equipment is an important part of conducting proper turbidity measurements, but operators should be aware of other factors in the process that may lead to poor-quality data. Such factors include poor lab techniques, calculation mistakes, malfunctioning or poorly functioning instrumentation, and out-of-date or deteriorated chemicals.

Development of a quality assurance and quality control (QA/QC) program can help ensure that lapses leading to inaccurate measurements or erroneous reporting do not occur.

Systems should maintain records and logs of all turbidimeter maintenance activities. Systems may also want to consider separate log books for each turbidimeter. Separate log books may allow the operators to better track the performance of each turbidimeter and could help them recognize instruments that drift out of calibration and may need to be replaced. Separate log books may also assist future operators by tracking maintenance procedures, such as the frequency of cleaning. In some situations, however, separate log books for each turbidimeter may not be the best option. Ultimately, systems should determine what turbidimeter tracking method works best for them.

3.8.1 QA/QC Organization and Responsibilities

A QA/QC plan should be clearly organized. For larger systems with more personnel, this plan should include an organizational chart with a section that assigns responsibilities to specific personnel for each part of the plan. This section should include a list of personnel positions (by title) and the responsibilities associated with each position. The appropriate training or skills necessary for each of the positions listed should also be included.

3.8.2 QA/QC Objectives

The objectives of the QA/QC program should be laid out and understood by management and staff members. Systems may wish to include one primary objective, followed by a number of goals that relate to the objective. Objectives should be specific and clear. An example might look like the following:

> ### Example QA/QC Plan
>
> The primary objective of the QA/QC program is to ensure that turbidity measurements are accurate and consistent. Based on this objective, the goals of the QA/QC program should include the following:
>
> - To adhere to proper sampling techniques as set forth in the SOPs.
>
> - To maintain and operate all turbidimeters at the plant properly in accordance with manufacturer instructions and SOPs.
>
> - To calibrate instruments on a routine and as-necessary basis.
>
> - To provide the necessary training to allow proper operation and maintenance of turbidimeters
>
> - To communicate and report all turbidimeter malfunctions, abnormalities, or problems that may compromise the accuracy and consistency of turbidity measurements.

3.8.3 SOPs

SOP = Standard Operating Procedure

SOPs are a way to ensure that activities are accomplished in an accurate, consistent manner and that each activity is understood by all involved. SOPs should be kept as simple as possible in order to ensure that each operator is consistent in carrying out the task at hand. The title of the procedure should be clear, concise, and descriptive of the equipment, process, or activity. SOPs should be developed with input from staff members, enabling them to effectively conduct work activities in compliance with applicable requirements. Systems should consider adopting SOPs for activities such as:

- Cleaning turbidimeters;

- Creating Formazin standards;

- Calibrating turbidimeters;

- Referencing index samples; or,

- Verifying turbidimeters.

Operators should be involved in writing SOPs to ensure the procedures are accurate, feasible, and make sense.

Instructional steps should be concise, precise, and use the following guidelines:

- Each step should contain only one action.

- Limits and/or tolerances for operating parameters should be specific values that are consistent with the accuracy of the instrumentation. Procedures should not include mental arithmetic.

- **"Cautions"** should be used to attract attention to information that is essential to safe performance.

- **"Notes"** should be used to call attention to important or supplemental information. Notes present information that assists the user in making decisions or improving task performance.

- Documentation methods should be incorporated as part of the procedure including what data needs to be recorded, whether the individual needs to sign or date data, etc.

- Identification and location of equipment necessary to perform procedures outlined in SOPs should be specified.

After developing an SOP, the author(s) should consider the following questions:

- Can the procedure be performed in the sequence as written?

- Can the user locate and identify all equipment referred to in the SOP?

- Can the user perform the procedure without needing to obtain direct assistance or additional information from persons not specified by the SOP?

- Are words, phrases, abbreviations, or acronyms that have special or unique meaning to the procedure adequately defined?

- Is there a need for special controls on data collection and recordkeeping?

When instrument or process changes occur that affect procedures, you should remember to update the appropriate SOP to reflect the change and inform all affected personnel.

After completing the SOP it should be tested to the extent possible. It is also a good idea to ask a technical reviewer to verify the accuracy of the SOP. SOPs should be reviewed routinely to determine if the procedures and requirements are

still accurate. As equipment is replaced or other operational changes are made, the SOPs should be reviewed and updated accordingly.

The following is a simplified example of an SOP written for the development of Formazin (4,000 NTU standard):

**Example SOP for Preparing
4,000 NTU Formazin Standard**

1. Dissolve 1.000 g of ACD grade hydrazine sulfate, $N_2H_4 H_2SO_4$, in ultra filtered deionized water and dilute to 100 mL in a Class A 100 mL volumetric flask.

2. Dissolve 10.00 g of analytical grade hexamethylenetetramine, $(CH_2)_6N_4$, in ultra filtered deionized water and dilute to 100 mL in a Class A 100 mL volumetric flask.

3. Combine the 100 mL of hydrazine sulfate solution and the 100 mL of hexamethylenetetramine solution in a clean, dry flask that is large enough to allow mixing (a 500 mL flask is best) and mix thoroughly.

4. Let the mixture stand for 48 hours at approximately 75° F (24° C) in a covered container.

5. Store in a properly labeled bottle that displays the standard (4,000 NTU Formazin), the date prepared, the expiration date, and the preparer's name.

6. Store the suspension in a bottle that filters ultraviolet light at a temperature between 40° F (5° C) and 75° F (24° C). Before using the suspension, allow it to come to room temperature.

Feedback from an audit in the form of a report, staff meeting, or other means may aid operators.

3.8.4 Performance and System Audits

Performance and system audits should be conducted periodically to determine the overall accuracy of the sampling and measurement systems, as well as to test the accuracy of each instrument. Performance audits may include reviews of documentation and log books to make sure that they are legible and complete. During the audit, all components of the sampling and measurement procedures should be evaluated to determine the best methods to be used for sampling,

calibration, and other operational-related procedures. This audit should include a careful evaluation of both field and laboratory quality control procedures. It can verify that SOPs work correctly, that the personnel understand the procedures, and that procedures are carried out and recorded properly.

3.9 REFERENCES

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4. DATA COLLECTION AND MANAGEMENT

In this Chapter:
- Data Collection Methods
- Data Management
- Data Management Tools
- System Upgrades to Consider

4.1 INTRODUCTION

Water systems subject to individual filter effluent turbidity monitoring will be faced with the task of collecting and managing much more data than they have in the past. The requirements in the LT1ESWTR will result in more time associated with collecting, analyzing, reporting, and managing data. Upgrades to the treatment plant may also be needed to install new or additional turbidimeters. Systems should consider how best to collect and manage the data, what additional equipment will be needed, and whether to use a computer to assist with data collection and management.

Remember, only conventional and direct filtration systems are required to continuously monitor individual filter effluent turbidity. This chapter contains information on how conventional and direct filtration systems may want to modify data collection and management processes. Systems using filtration technologies other than conventional and direct may find some useful information (refer to Sections 4.4.2 and 4.4.3), but this chapter primarily focuses on conventional and direct filtration systems.

4.2 DATA COLLECTION METHODS

Many methods of data collection exist. Systems may be using grab samples and benchtop units to comply with the 4-hour combined filter effluent readings. Readings from benchtop units are typically recorded by hand or entered into a computer without the use of data collection equipment. Grab samples are generally not feasible for individual filter readings because these samples must be taken every 15 minutes (for conventional and direct filtration systems). Therefore, systems will likely use on-line, continuous recording turbidimeters. Continuous turbidity readings can be recorded by strip recorders, data loggers, or supervisory control and data acquisition (SCADA) systems.

See Chapter 3 for more information on calibrating turbidimeters.

If using strip charts or circular charts, you should make sure the scale is set such that values can be read accurately.

For more information on instrumentation and control, refer to the American Water Works Association's (AWWA's) manual *Instrumentation and Control*, 3rd edition.

Data obtained from strip charts, data recorders, and SCADA systems should be verified at least annually by comparing the turbidimeter reading with the data recording device reading. If verification indicates greater than " 10 percent deviation, the electronic signal should be recalibrated according to the manufacturer's instructions.

4.2.1 Strip Recorders and Circular Chart Recorders

Strip chart and circular chart recorders are relatively well-established equipment for recording data. The recording units are set to obtain a reading at a timed interval. A pen records the reading on paper. As additional readings are taken, the pen moves back and forth (or up and down, in the case of a circular recorder), recording the values that are being monitored.

Newer models include digital readouts and the capability to transfer data to data loggers or other data acquisition systems. The greatest disadvantage to using chart recorders is the difficulty in incorporating data into electronic format and archiving the data. Recorders also require the purchase of replacement pens and charts.

Some paper chart recorders have the option of using either a 24-hour or 7-day chart. For individual filter monitoring, systems should consider using a 24-hour chart that can record measurements at 15-minute increments.

When using a chart recorder, the range should be set to allow turbidities of 2.0 NTU to be accurately recorded for individual filter effluent turbidity monitoring (see Section 2.1.2).

4.2.2 Data Loggers

Data loggers are "black boxes" that store data received from input channels. The box records the data in memory that can then be downloaded at a future time. Data loggers consist of two distinct components: hardware and software.

Hardware

The units typically consist of a device containing solid state memory encased in a plastic weatherproof enclosure. Units can record either analog (actual numbers) or digital (a series of 0s and 1s) inputs and also have an output port for downloading

data. Systems can be battery powered or connected to a power supply. Nearly all systems contain lithium or other types of batteries to keep memory active in the event of a power failure.

Software

Data loggers and acquisition devices have two software components. First, specialized software is necessary to configure the logging unit to take turbidity readings at the desired frequency. The second part of the software retrieves the data from the logger and exports it into a usable format on a personal computer. Most companies offer packages that enable users to export data to a computer and immediately plot and graph the data to depict trends or produce reports. Data should be downloaded to a computer at regular intervals, because data loggers cannot store data indefinitely.

Several methods exist to transfer data from the logger to the computer. Data acquisition systems are often equipped to be compatible with telemetry to upload data to personal computers via telephone, cellular telephone, or radio. Alternatively, either a laptop or palmtop can be connected to the unit to download information, or the data logger can be brought into the office where the computer is located and plugged into one of the input/output ports on the computer. Systems may want to have a second data logger to take the place of the first logger when it is being downloaded to avoid missing readings. Systems may wish to schedule downloads to occur at times when a filter is not in operation (e.g., when off-line or during backwash).

4.2.3 SCADA

SCADA systems are devices used for measurement, data acquisition, and control. They consist of a central host (base unit), one or more field gathering and control units (remotes), and software that monitors and controls remotely located field data elements. The base unit and the remote units are linked via telemetry, and the base unit controls the remote units and receives data. Control may be automatic or initiated by operator commands.

SCADA systems can collect and display inputs from a variety of sources and instruments, so the plant operator can monitor the entire treatment process from one (or many) location(s). SCADA systems are typically used for flow control, pH, turbidity, and temperature monitoring, automated disinfection

The combined filter effluent must be recorded every 4 hours and the individual filter effluent must be recorded at least every 15 minutes for conventional and direct filtration systems. However, better process control may be achieved by collecting measurements more often than 15 minutes.

dosing, and a host of other functions. A SCADA system can be configured to record individual filter effluent turbidity measurements every 15 minutes, as required by the LT1ESWTR for conventional and direct filtration systems.

Figure 4-1. Central SCADA Unit

SCADA systems can also be used to log and store data for recording purposes. Signals are sent from remote instruments located on the plant site to the base unit. This unit interprets all of the different signals and displays real-time measurements. It can be programmed to automatically transfer data to other storage media such a tape drive or a Zip® disk.

SCADA allows real-time monitoring from a remote location.

Figure 4-2. SCADA Control Monitor

Figure 4-3. SCADA Control Room

It is important for the operator to check the readings on the SCADA against readings from the field. For instance, if a 4-20 milliamp (mA) signal comes out of a turbidimeter and into a computer, two separate calibrations should be done. If a 20 mA raw signal (high end) correlates with 100 NTUs on the turbidimeter but only 98 NTUs on the SCADA, this means there is an accuracy and reporting problem. The reported SCADA values are too low and the electronic signal will probably need to be recalibrated.

4.3 DATA MANAGEMENT

There are two objectives for turbidity data management: (1) regulatory compliance, and (2) process control and treatment plant optimization. The turbidity reporting and monitoring requirements are described in Chapter 2. In order to meet these requirements, operators should understand three areas of data management:

- Data format;
- Data storage; and,
- Data analysis.
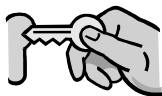
As part of data management, it is strongly recommended that systems frequently back up electronic data, for example, every 24 hours and keep all hard copy records.

Spreadsheets for turbidity data management are available from the Partnership for Safe Water (http://www.awwa.org/ science/partnership or 303-347-6169) or in EPA's *Optimizing Water Treatment Plant Performance Using Composite Correction Program*, 1998 Edition.

When a water system understands the dynamics of its filtration system by analyzing turbidity data, turbidity values that deviate from the norm will be easier to troubleshoot.

4.3.1 Format

Formatting the data into a usable form should be the first step in effective data management. Operators should have the ability to download data from their acquisition equipment in a usable and manageable format. Data should be placed in one of many different spreadsheet formats and databases. Certain software packages allow users to create reports, tables, or graphs based on the data. The key to selecting a format is the ease with which the data can be viewed, manipulated, and converted.

4.3.2 Storage

Storage of the data should be the next step in effective data management. Maintaining data points for future analysis may pose a problem due to the amount of disk space required. Systems should consider the use of Zip$^®$ disks, data CDs, or tapes to store data. Computer hard drives can be used to temporarily store data while it is being analyzed, but the system should have CD, tape, or Zip$^®$ disk backups in case the computer crashes. You should contact the State or primacy agency to coordinate data storage protocol.

4.3.3 Interpreting and Analyzing Data

Data analysis should be the last step in effective data management. One good approach is to use a spreadsheet or database that can generate reports, tables, graphs, and filter profiles, as suggested in Section 4.3.1. The worksheets in Appendix B can also be used. You should check with the State before using the worksheets to make sure all the information required by the State is included in the forms. Some States have already created spreadsheet-based forms and could show systems how to use them.

Analyzing turbidity data is useful because it allows systems to determine how well a process is being controlled over time and to identify and understand turbidity trends, which will assist in plant optimization. With adequate data collection, systems could evaluate post-backwash turbidity spikes for individual filters, the effect of storm events on the filtration capabilities, or the impact of various chemical dosages on filtered effluent. Analyses could be undertaken to compare different filters within a system or the effect of different flow rates. Chapter 5

provides information on how to conduct a filter self-assessment and other filter analyses.

4.4 DATA MANAGEMENT TOOLS

This section presents worksheets and spreadsheets that can be used to record and report data. Check with the State to determine the proper format for reporting turbidity readings.

4.4.1 Conventional and Direct Filtration Systems

Combined Filter Effluent

Check with the State before adopting the worksheets in this document. States may have their own worksheets or may require some additional or different information.

One way to report combined filter effluent readings is to use Worksheet 1 (located in Appendix B). A completed example of Worksheet 1 is included later in this section. You should check with the State before using this worksheet to ensure that all of the required information is reported.

Combined filter effluent values must be recorded every 4 hours during plant operation. For plants that operate 24 hours a day and discharge combined filter effluent continuously to the clearwell, the 4-hour intervals are easily determined. For instance, combined filter effluent readings can be taken at 12:00 a.m., 4:00 a.m., 8:00 a.m., 12:00 p.m., 4:00 p.m., 8:00 p.m., and so on. Plants that operate intermittently will have a more difficult time determining the 4-hour intervals.

Suggested guidelines for systems that do not operate 24 hours per day.

The following are some suggested guidelines for determining the recording intervals for plants that do not operate 24 hours a day:

- Time begins (t=0) when the system starts discharging filter effluent to the clearwell.

- If the plant operates for more than 4 hours per day, you may record the combined filter effluent any time during the first 4 hours of operation and then every 4 hours from the time of the initial turbidity sample. For instance, say the plant starts discharging to the clearwell at 6:00 a.m. and the first combined filter effluent turbidity reading is taken at 10:00 a.m. The operator would need to take the next turbidity readings at 2:00 p.m., 6:00 p.m., and 10:00 p.m. The plant stops discharging to the clearwell at 11:30 p.m., so the

If spreadsheet software is available, consider generating a worksheet on the computer. If formulas are already programmed in the spreadsheet, entering data to calculate compliance for combined filter effluent turbidities will require less time and ensure greater accuracy.

operator would not need to take any additional readings until the plants starts discharging to the clearwell again.

- If the plant operates for less than 4 hours at a time, you should record the turbidity values at the end of each operating period.

Once the combined filter effluent values have been recorded, the operator should calculate the percentage of readings less than or equal to 0.3 NTU. LT1ESWTR requires 95 percent of the monthly readings to be less than or equal to 0.3 NTU for conventional and direct filtration systems. The following page provides an example of a completed worksheet and how to calculate the 95th percentile reading.

You should check with the State for any recording or reporting policies or requirements for plants that do not operate 24 hours a day.

SAMPLE WORKSHEET 1
CONVENTIONAL AND DIRECT FILTRATION PLANTS
MONTHLY REPORT FOR COMBINED FILTER EFFLUENT
Due by the 10th of the Following Month

Check with your State or Primacy Agency to make sure this form is acceptable.

Month: May

System/Treatment Plant: Townville

Year: 2005

PWSID: AB1234567

A	B	C[1]	D[2]	E	F
	Number of Samples Required Per Day	Maximum Combined Filter Effluent	No. of Turbidity Measurements	No. of Turbidity Measurements <= 0.3 NTU	No. of Turbidity Measurements >1 NTU
Day	Samples/Day	NTU	Measurements		
1	6	0.2	6	6	0
2	6	0.1	6	6	0
3	6	0.4	6	5	0
4	6	0.4	6	5	0
5	6	0.2	6	6	0
6	6	0.1	6	6	0
7	6	0.5	6	4	0
8	6	0.2	6	6	0
9	6	0.1	6	6	0
10	6	0.1	6	6	0
11	6	0.1	6	6	0
12	6	0.1	6	6	0
13	6	0.1	6	6	0
14	6	0.1	6	6	0
15	6	0.1	6	6	0
16	6	0.1	6	6	0
17	6	0.1	6	6	0
18	6	0.1	6	6	0
19	6	0.1	6	6	0
20	6	0.1	6	6	0
21	6	0.1	6	6	0
22	6	0.1	6	6	0
23	6	0.1	6	6	0
24	6	0.1	6	6	0
25	6	0.1	6	6	0
26	6	0.1	6	6	0
27	6	0.1	6	6	0
28	6	0.1	6	6	0
29	6	0.1	6	6	0
30	6	0.1	6	6	0
31	6	0.1	6	6	0
		Totals:	186	182	0

Number of monthly readings (Total of Column D) = 186

Number of monthly readings <= 0.3 NTU (Total of Column E) = 182

The percentage of turbidity measurements meeting the specified limits.

= (Total of Column E / Total of Column D) x 100 = 98 %

Record the date and turbidity value for any measurements exceeding 1 NTU (Contact State within 24 hours):
If none, enter "None."

Prepared by: J. Operator

Date: June 3, 2005

Date	Turbidity Readings > 1 NTU
	None

Was individual filter effluent monitored continuously (at least every 15 minutes) during the month?
Yes __X__ No _____

Individual Filter Effluent

You should check with the State for acceptable forms for reporting and recording individual filter effluent turbidity data. Chapter 2 presents the monitoring, reporting, and recordkeeping requirements for individual filters.

The LT1ESWTR will require conventional and direct filtration systems with more than two filters to take individual filter turbidity effluent readings every 15 minutes. Sample Worksheet 2 (located in Appendix B) can be used for recording turbidity data from a filter. Remember, if any individual filter reading exceeds 1.0 NTU in two consecutive 15-minute readings, then the system must report the filter number(s), corresponding date(s), turbidity value(s) that exceeded 1.0 NTU, and the cause (if known) for the exceedances (see Section 2.1.2). This information is due to the State by the 10th of the following month.

The 15-minute readings should begin when the system starts discharging individual filter effluent to the clearwell and should continue until the filter is taken off-line.

Following is a completed excerpt from sample Worksheet 2.

SAMPLE WORKSHEET 2
CONVENTIONAL AND DIRECT FILTRATION PLANTS
MONTHLY SUMMARY REPORT OF DATA FOR INDIVIDUAL FILTER EFFLUENT
Check with your State or Primacy Agency to make sure this form is acceptable.

Year:____2005_____   System Name:__Anytown PWS___
PWSID:__NY1234567   Filter Number:___3_____

A	B	C	D
Date	Were 15-min Turbidity Values Recorded?	Values of Turbidity Measurements > 1.0 NTU for two or more consecutive 15-min readings	Value of Turbidity Measurements > 2.0 NTU for two or more consecutive 15-min readings
2/5	Yes	1.1, 1.2	
2/8	Yes	1.1, 1.15, 1.1	

Did the filter exceed 1.0 NTU in two or more consecutive 15-minute readings this month? _____ No
___X__ Yes - Report to the State by the 10th of the following month the filter number(s), corresponding date(s), and turbidity value(s) which exceeded 1.0 NTU and the cause, if known.
Did this occur in the two previous months? _X__ No
_____ Yes - Must conduct a filter self-assessment within 14 days of the exceedance unless a CPE was required.
Did the filter exceed 2.0 NTU in two or more consecutive 15-minute readings this month? _X__ No
_____ Yes - Did this occur in the previous month? _____ No
_____ Yes - Must arrange for a CPE unless a CPE has been completed by the State or third party approved by the State within the 12 prior months or the system and State are jointly participating in an ongoing Comprehensive Technical Assistance project at the system.

4.4.2 Slow Sand and Diatomaceous Earth Filters

The requirements for slow sand and diatomaceous earth filters have not changed from the requirements in the Surface Water Treatment Rule. Systems must still take combined filter effluent readings every 4 hours, with a maximum allowed turbidity of 1 NTU in at least 95 percent of the measurements taken each month and 5 NTU in any single measurement (see Section 2.2). The State may allow less frequent measurements for slow sand systems. Sample Worksheet 3 (located in Appendix B) can be used to record and report turbidity readings. Monitoring individual filters in slow sand and diatomaceous earth filtration systems is not required by the LT1ESWTR. However, the operator may choose to monitor individual filters for optimum plant performance.

4.4.3 Alternative Filtration Technologies

The State is expected to establish the turbidity limits and frequency of measurements for alternative filtration technologies, such as membranes or cartridges. Sample Worksheet 3 (located in Appendix B) can be used to record and report data. The monitoring, reporting, and recordkeeping requirements for alternative filtration technologies are presented in Section 2.3.

4.5 WHAT UPGRADES SHOULD I CONSIDER FOR MY SYSTEM?

The LT1ESWTR requires the collection, analysis, reporting, and storage of a larger volume of data than previously collected. As a result, more personnel time may be required to maintain instruments and to collect and report data. Systems may also need to develop financing (and may need to generate additional revenue) to purchase additional equipment.

Conventional and direct filtration systems that do not currently have the capability to monitor individual filter effluent turbidity will need to install turbidimeters and the necessary equipment to record individual filter effluent turbidities every 15 minutes. The turbidimeter and associated equipment used to monitor and record individual filter effluent turbidity should be capable of

The monitoring, reporting, and recordkeeping requirements for slow sand, diatomaceous earth, and alternative filtration systems are presented in Chapter 2.

The system should properly plan for anticipated staff and revenue needs to achieve compliance with the LT1ESWTR.

the following:

- Recording individual filter effluent turbidity readings at least every 15 minutes per LT1ESWTR;

- Compiling turbidity readings on a monthly basis; and,

- Tracking instances when the turbidity values exceed 1.0 NTU for two consecutive measurements because follow-up actions are required.

Systems that cannot record, track, or store turbidity measurements with their existing turbidimeter and associated equipment to comply with LT1ESWTR requirements may consider incorporating one of the following configurations (assuming the analyzer/controller portion of their turbidimeter unit has 0-20 mA or 4-20 mA capabilities) into their turbidimeter units:

- Connecting the turbidimeter unit to a data or strip chart recorder to record, track, and store data;

- Hardwiring the turbidimeter unit to a Programmable Logic Controller (PLC) or SCADA system; or,

- Providing necessary connection to allow data to be downloaded from the turbidimeter unit to a lap-top computer.

In order to implement some of these and other changes, systems may evaluate new equipment or upgrades for their turbidimeters, data recorders, controllers, and other system components. The following list contains issues the operator and system owner may want to consider during this evaluation:

System upgrades and modifications require a lot of considerations.

- Is the turbidimeter intended for measurements over the expected operational range (such as 0.01 – 5 NTUs)? Systems may not want a device that cannot handle low-range turbidities.

- Will the system need to upgrade the electrical service to its building in order to accommodate more and different equipment?

- Can the analyzer portion of the turbidimeter unit display turbidity level alarms in situations where SCADA or data chart recorders are not used? Alarms should be displayed in some fashion so that operators can address filter issues in a timely manner. For instance, alarms could be initiated if the individual filter effluent

turbidity approaches 1.0 NTU.

- Can the turbidimeter data be downloaded and a filter profile be generated?

- What type of alarm system does the turbidimeter have? The system may want to have multiple alarm capabilities (an alarm if individual filter effluent turbidity approaches 1.0 NTU, a separate alarm for individual filter effluent turbidity that approaches 2.0 NTU, and an alarm for combined filter effluent that approaches 0.3 NTU).

- Can the operator be notified when the alarms are activated? Operators may want a mechanism that notifies them by pager or other means when trigger turbidity values occur.

- Is there local support for repair and maintenance of turbidimeters? Systems should make sure a manufacturer's representative can be at the plant on short notice.

- What experiences have other systems had? Operators may want to consult nearby utilities to see which turbidimeters they are using and to discuss what has and has not worked for them.

4.5.1 Suggested System Configuration

The following descriptions of three turbidimeters may help the operator get started with where to look and what to look for when selecting a turbidimeter.

The following does not constitute an EPA endorsement or recommendation for use. The listed turbidimeters are just a few of the units available to measure turbidity that EPA is aware of. Please let us know if there are other manufacturers which were not represented. Systems may use any turbidimeter provided it can be used with an EPA-approved method.

Many turbidimeters and data logging equipment exist. You should make sure all equipment is compatible and can be used to meet all applicable monitoring, reporting, and recordkeeping requirements.

HACH 1720D:

- The Hach 1720D is a low-range process turbidimeter with power supply and one AquaTrend® Interface with Signal Output Module.

- Power requirements: 95-240 Vac, 50/60 Hz, auto-select, 40 VA.

- Recorder outputs: selectable for 0-20 or 4-20 mA.

- Measures turbidity from 0.001-100.0 NTU.

- A single AquaTrend® Interface can network up to eight 1720D Turbidimeters from eight individual filters; it provides a significant hardware cost savings in installations where multiple sensors are required.

- No sample cell to clean, reducing maintenance and downtime.

- Response time: 1 minute and 15 seconds; allows consecutive 15-minute readings.

- Calibration time: about 1 minute and 45 seconds.

- Stores up to 30 days worth of readings, allowing monthly generation of a filter profile. Data can be downloaded to a computer.

- Two alarms: low range and high range. Also has system alarms.

When selecting monitoring and data analyzing equipment, you should verify that a supplier representative is available to respond to problems in a timely manner.

HF Scientific MicroTOL:

- Power requirements: 100-250Vac, 50/60 Hz, wall adapter.

- Analog Output: 4-20 mA.

- Digital Output.

- Designed for smaller systems.

- Sensor and analyzer are one unit.

- Measures turbidities from 0-1,000 NTU.

- Measures individual filter effluent turbidity every 15 minutes and combined filter effluent turbidity every 4 hours.

- Calibration time: 5 minutes or less.

- Response time: 1 to 20 seconds.

- Two alarms: low and high turbidities.

- Software available that allows logging, comparisons, graphs, and data acquisition from up to 256 on-line turbidimeters to a computer (RS-485).

Operators should be involved with equipment selection to avoid the purchase of improper or complicated equipment.

GLI International Accu4™ Low-Range Turbidimeter System:

- System consists of:

    1. Analyzer: T53A4AIN;

    2. Sensor: 8320TIA0C3N; and,

    3. Calibration Cube Assembly: 8220-1300.

- Operates in accordance with EPA-approved GLI Method 2 and ISO 7027 – 1984 (E).

- Power requirements: 90-130 or 180-260 VAC, 50-60 Hz.

- Analog outputs: Two isolated 0-20 mA, or 4-20 mA.

- Digital display.

- Measures turbidities from 0.000-100.0 NTU.

- Analyzer Performance:

    1. Accuracy: ± 2% of reading, all ranges;

    2. Stability: 0.1% of span; and,

    3. Repeatability: 0.1% of span or better.

- Optional Cal-Cube™ assembly to conveniently verify calibration.

- Alarms.

- Software available to allow download of data to IBM-compatible computers (RS-232).

4.6 REFERENCES

USEPA. 1998. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program (EPA 625-6-91-027). Washington, D.C.

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5. FILTER SELF-ASSESSMENT

Filter self-assessments are required only under certain circumstances for conventional and direct filtration systems (see Section 2.1.2). However, systems using filtration technologies other than conventional and direct may find some useful information in this chapter.

In this Chapter:

- Assessment of Filter Performance
- Development of a Filter Profile
- Identification and Prioritization of Factors Limiting Filter Performance
- Assessment of Applicability of Corrections
- Preparation of the Report

See Section 2.1.2 for more information on individual filter effluent turbidity monitoring requirements when a filter self-assessment is required and when a CPE is required.

5.1 INTRODUCTION

Conventional and direct filtration systems must conduct a filter self-assessment for any filter that has a turbidity level greater than 1.0 NTU in two consecutive measurements taken 15 minutes apart for three consecutive months unless a CPE as specified in 40 CFR Section 141.563(c) was required. Conventional and direct filtration systems that have no more than two filters and monitor combined filter effluent turbidity only, instead of individual filter effluent turbidity, must conduct a self-assessment on all of its filters if the combined filter effluent exceeds 1.0 NTU in two consecutive measurements taken 15 minutes apart for three consecutive months. The date the filter exceeded 1.0 NTU in two consecutive 15-minute readings for the third consecutive month is called the trigger date. The filter self-assessment must be conducted within 14 days of the trigger date. Systems must report to the State that the filter self-assessment was required, the trigger date, and the date the filter self-assessment was completed. This information is due to the State by the 10th of the following month (or 14 days after the self-assessment was triggered if the self-assessment was triggered during the last 4 days of the month). In addition, systems must report the filter number, the turbidity measurement, date on which the exceedances occurred, and reason for the exceedance (if known) in the monthly report due the 10th of the following month. Systems may also want to conduct a filter self-assessment whenever a filter's effluent quality indicates a potential problem, even if it is not required by the regulation.

40 CFR Section
141.563(b)
The filter self-assessment
must consist of at least the
following components:
- Assessment of the
  filter performance;

- Development of a
  filter profile;

- Identification and
  prioritization of
  factors limiting
  filter performance;

- Assessment of the
  applicability of
  corrections; and,

- Preparation of a
  filter self-
  assessment report.

The filter self-assessment must consist of at least the following components (40 CFR Section 141.563(b)):

- Assessment of the filter performance;

- Development of a filter profile;

- Identification and prioritization of factors limiting filter performance;

- Assessment of the applicability of corrections; and,

- Preparation of a filter self-assessment report.

Filters represent a key unit process for the removal of particles in surface water treatment. Although filters represent only one of the barriers in a treatment process, their role is the most critical as the final physical barrier to prevent pathogenic microorganisms that are resistant to disinfection from entering distribution systems. Properly designed filters, when in proper physical and operational condition and used in conjunction with coagulation, flocculation and/or sedimentation are capable of treating raw water to an acceptable level.

Filter performance problems may only be obvious during excessive hydraulic loading or chemical failure, but you should not assume all turbidity spikes are due to hydraulic overloading. In some circumstances performance problems from other causes may be evident only during these hydraulic episodes. This chapter describes the process of an individual filter self-assessment and is intended to provide information to help you assess which of these areas are limiting the performance of a filter.

This chapter describes some of the possible components of an individual filter assessment:

- An assessment of filter performance (Section 5.2).

  - A general description of the filter.

- The development of a filter profile (Section 5.3).

- Identification and prioritization of factors limiting filter performance (Section 5.4).

  - An assessment of the hydraulic loading conditions of the filter.

You should consult the State regarding the requirements and format of the filter self-assessment.

- An assessment of the actual condition and placement of the media.

- An assessment of the condition of the support media and underdrains.

- An assessment of backwash practices.

- An assessment of how the filter is placed back into service.

- An assessment of the filter rate-of-flow controllers and filter valving infrastructure adequacy.

- An assessment of other plant processes, such as chemical feed rates, raw water quality changes, and turbidimeters.

- An assessment of the applicability of corrections (Section 5.5).

- Preparation of the filter self-assessment report (Section 5.6).

You may want to perform filter self-assessments routinely as preventive maintenance.

The checklist in Figure 5-1 can be used to assist with the filter self-assessment. A blank copy of this checklist can be found in Appendix B.

System Name   XYZ Water System
Filter #   3
Date Self-Assessment was Triggered 6/3/05
Date of Self-Assessment 6/8/05

   ✓   Assessment of Filter Performance

   ✓   Development of a Filter Profile

   ✓   Identification and Prioritization of Factors
          Limiting Filter Performance

   ✓   Assessment of the Applicability of
          Corrections

   ✓   Preparation of a Filter Self-Assessment
          Report

Figure 5-1. Filter Self-Assessment Checklist

The information in Table 5-1 may be useful in assembling information required by the Filter Backwash Recycling Rule.

Table 5-1 can also be used to assist with the filter self-assessment process. The Filter Self-Assessment video (under development) provides guidance on collecting the information to complete Table 5-1. Equations in Appendix C may also be helpful in completing the table. You may already have the information needed to complete Table 5-1, while others may have to collect or verify the needed information. The following sections will explain how to collect and verify information.

Table 5-1. Sample Individual Filter Self-Assessment Form[†]

Topic	Description	Information	
		Actual	**Design**
General Filter Information	Type (mono, dual, mixed, pressure, gravity)		
	Number of filters		
	Filter/rate control (constant, declining)		
	Type of flow control (influent weir, valves)		
	Surface wash type (rotary, fixed, none)/air scour		
	Configuration (rectangular, circular, square, horizontal, vertical)		
	Dimensions (length, width, diameter, height of side walls)		
	Max depth of water above media		
	Surface area per filter (ft^2)		
Hydraulic Loading Conditions	Average operating flow (mgd or gpm)		
	Peak instantaneous operating flow (mgd or gpm)		
	Average hydraulic surface loading rate (gpm/ft^2)		
	Peak hydraulic surface loading rate (gpm/ft^2)		
	Changes in hydraulic loading rate (gpm/ft^2)		
Media Conditions	Depth, type, uniformity coefficient[*], and effective size[*]		
	Media 1		
	Media 2 (if applicable)		
	Media 3 (if applicable)		
	Presence of mudballs, debris, excess chemical, cracking, worn media, media coating		

[†]This worksheet is designed to elicit additional information and is not required under 40 CFR Section 141.563(b).

*You may want to have a sieve analysis done on the media. Note that a sieve analysis may not be able to be completed within the 14-day time frame required for a filter self-assessment.

Table 5-1. Individual Filter Self-Assessment Form (continued)

Topic	Description	Information	
		Actual	**Design**
Support Media/Under-drain Conditions	Is the support media evenly placed (deviation <2 inches measured vertically) in the filter bed?		
	Type of underdrains		
	Evidence of media in the clearwell or plenum		
	Evidence of boils during backwash		
Backwash Practices	Backwash initiation (headloss, turbidity/particle counts, time)		
	Sequence (surface wash, air scour, flow ramping, filter-to-waste)		
	Duration (minutes) of each step		
	Introduction of wash water (via pump, head tank, distribution system pressure)		
	Backwash rate (gpm/ft^2) at each step		
	Bed expansion (percent)		
	Dose of coagulants or polymers added to wash water		
	Backwash termination (time, backwash turbidity, visual inspection, or other)		
	Backwash SOP (exists and current)		
Placing a Filter Back into Service	Delayed start, slow start, polymer addition, or filter to waste		
Rate-of-Flow Controllers and Filter Valves	Leaking valves		
	Malfunction rate of flow control valves		
	Equal flow distribution to each filter		
Other Considerations	Chemical feed problems		
	Rapid changes in raw water quality		
	Turbidimeters (calibrated)		
	Other		

Note: Excerpts from this table including sample data can be found throughout this chapter. An additional blank copy of this form is found in Appendix B.

5.2 ASSESSMENT OF FILTER PERFORMANCE

Topic	Description	Information Actual	Information Design
General Filter Information	Type (mono, dual, mixed, pressure, gravity)	dual	dual
	Number of filters	4	4
	Filter/rate control (constant, declining)	constant	constant
	Type of flow control (influent weir, valves)	valves	valves
	Surface wash type (rotary, fixed, none)/air scour	fixed	fixed
	Configuration (rectangular, circular, square, horizontal, vertical)	rectangular	rectangular
	Dimensions (length, width, diameter, height of side walls)	length = 10 ft width = 8 ft height = 12 ft	length = 10 ft width = 8 ft height = 12 ft
	Max depth of water above media	6 ft	6 ft
	Surface area per filter (ft^2)	80 ft^2	80 ft^2

Excerpt from Table 5-1 containing sample data. Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

You should evaluate overall performance of the filter(s) being assessed. For instance, you may want to further investigate any of the following observations:

- Filter has required more frequent backwashing than usual;

- Filter has experienced shorter run times; or,

- Unusual events (such as boiling) have been noticed during backwashing.

You may wish to also examine the historical performance of other filters at the plant to determine if the problem is filter specific.

These items are just some of the filter performance issues that should be investigated further during a filter self-assessment.

5.3 DEVELOPMENT OF A FILTER PROFILE

A filter profile must be developed as part of the filter self-assessment process. The purpose of this requirement is to help you identify turbidity spikes (sudden increases in turbidity) or high turbidity levels during the filter run and to determine the probable causes of those spikes. The profile for the filter being evaluated should include a graphical summary of filter performance for an entire filter run from start-up (when filtered water goes to the clearwell) to the time the filter is taken off-line. Performance should be shown by turbidity or particle count measurements. Plotting the performance data versus time on a continuous basis is one good approach for development of the filter profile (see Figures 5-2 through 5-7). While the LT1ESWTR requires recording turbidity measurements at least every 15 minutes for purposes of developing a filter profile, you may want to consider taking turbidity readings once every 5 minutes, every minute, or more frequently. This increased frequency will allow you to more accurately capture spikes. The filter profile should represent a typical run and should include (if representative of normal filter operations) the time period when another filter is being backwashed or is out of service (in order to determine if such practices have an impact on finished water quality). The filter profile should include an explanation of the cause (if known) of performance spikes during the run. You should identify flow and changes in flow to the filter on the filter profile. When possible, plot the profile using data collected during the turbidity event that prompted the filter self-assessment. If assistance is needed with this portion of the filter assessment, you may contact your State. Figures 5-2 through 5-7 are examples of filter profiles with explanations of each profile.

Remember, you are required to continuously monitor and record the individual filter effluent turbidity at least every 15 minutes. If readings are taken more frequently than 15 minutes, you should check with the State on how to report this information.

The use of particle counting in conjunction with turbidity monitoring of filter effluent may offer additional insights to filter performance; however, care should be taken in the interpretation of particle count results. The interpretation should focus on the change in count levels as opposed to the discrete particle count numbers.

Figure 5-2. Example Filter Profile of Optimized Filter Performance
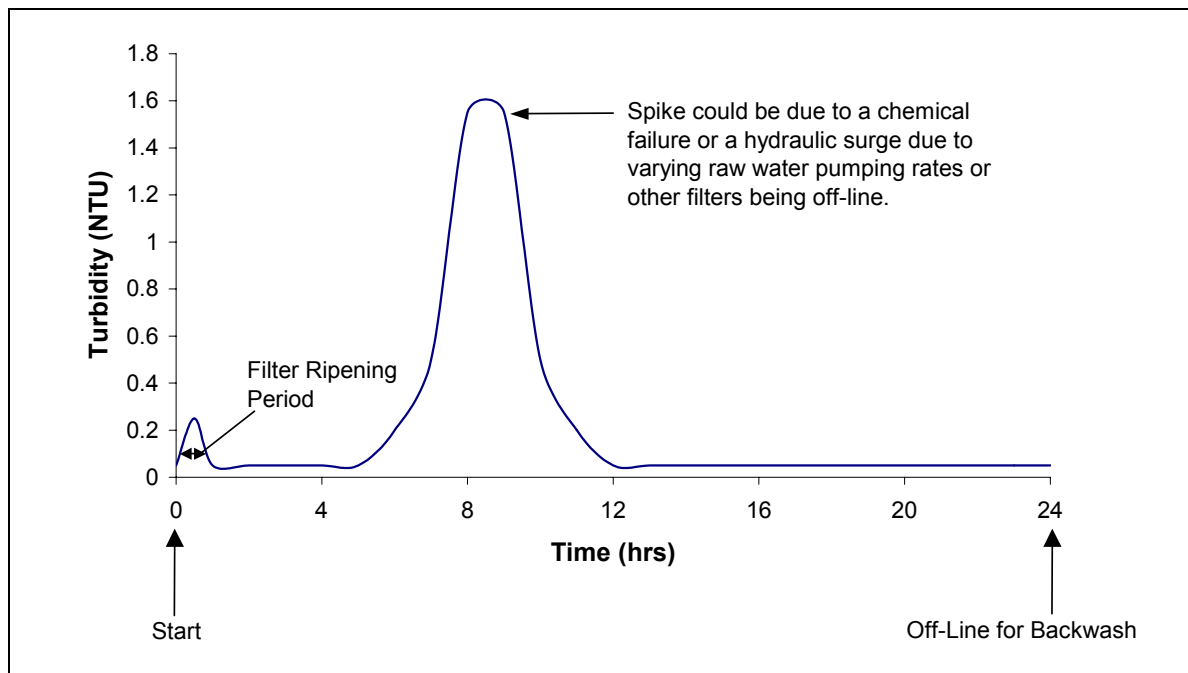
**Figure 5-3. Example Filter Profile of Optimized Filter
with Turbidity Spike During Filter Run**
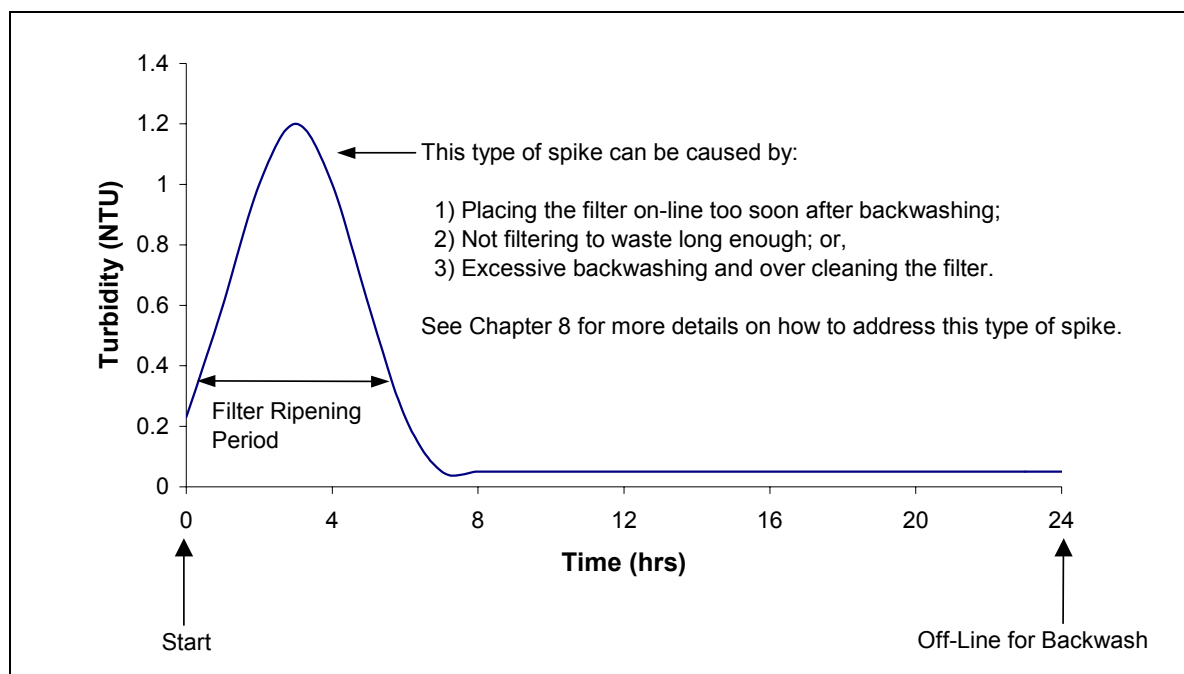
Figure 5-4. Example Filter Profile with Long and High Initial Spike
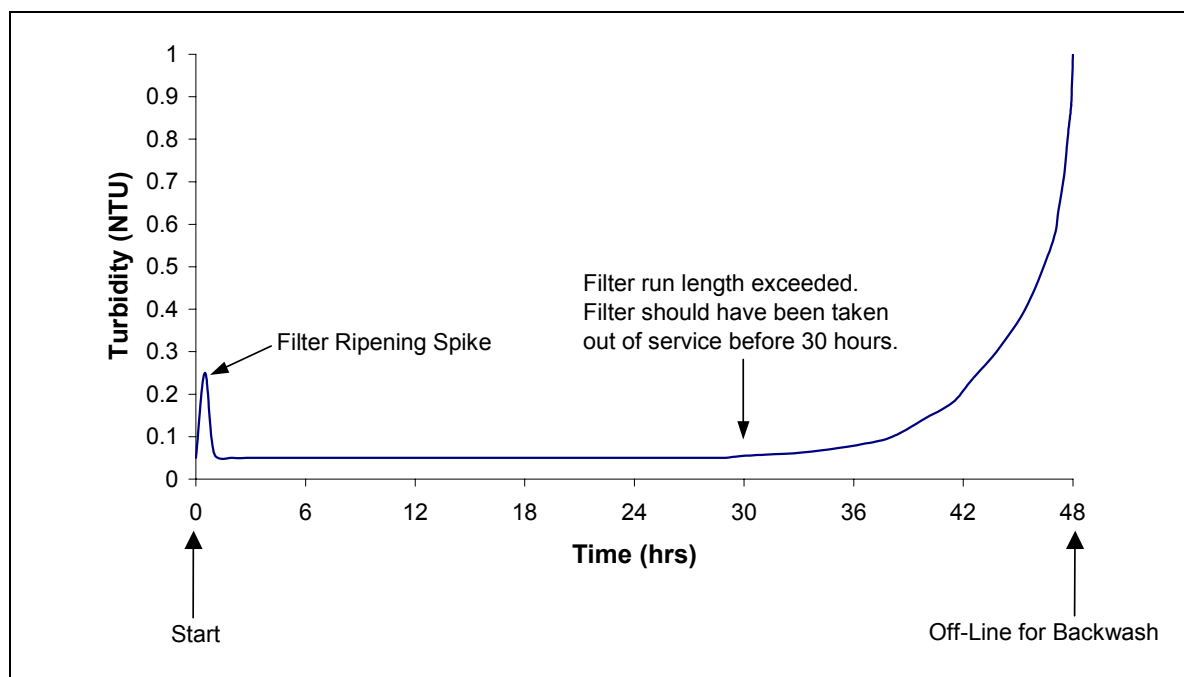
**Figure 5-5. Example Filter Profile of Optimized Filter
with Breakthrough at End of Filter Run**
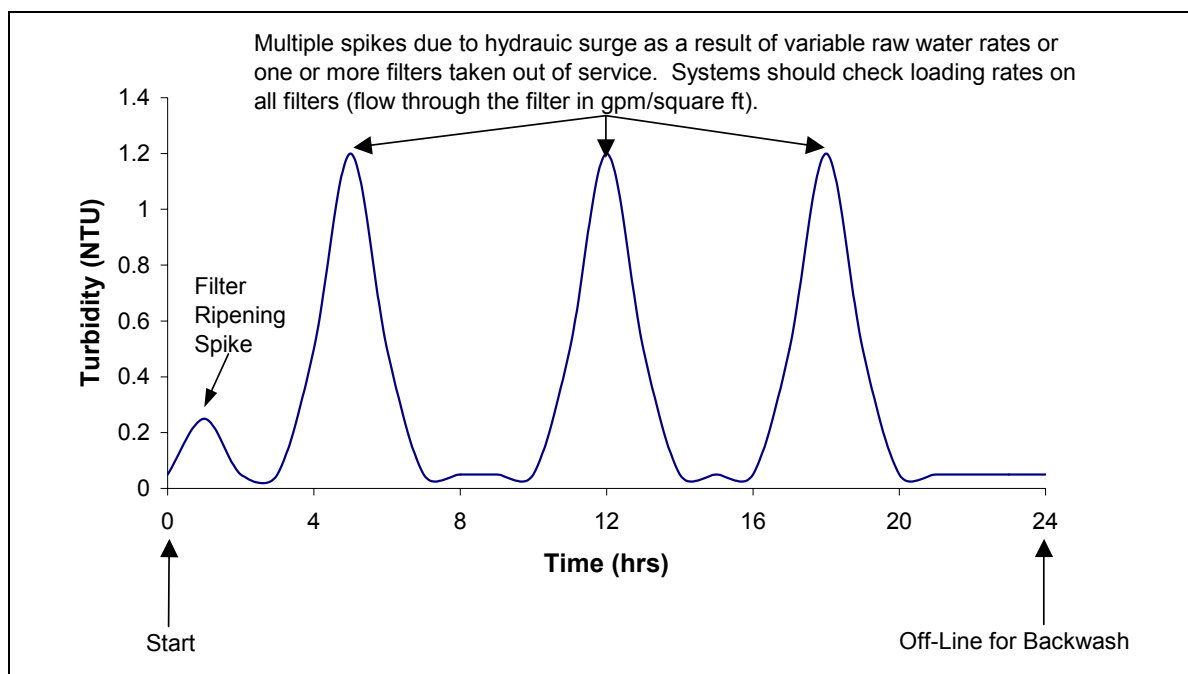
Figure 5-6. Example Filter Profile with Multiple Spikes
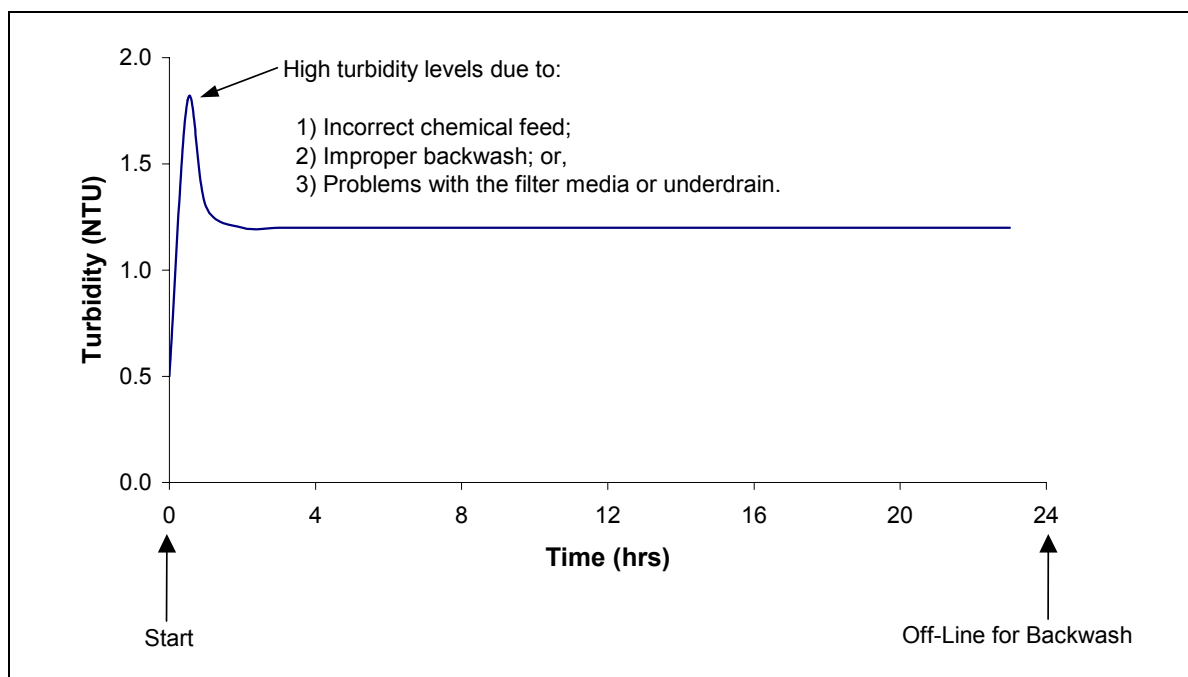
**Figure 5-7. Example Filter Profile with High Initial
Spike and Turbidity Levels Above 1.0 NTU**

5.4 IDENTIFICATION AND PRIORITIZATION OF FACTORS LIMITING FILTER PERFORMANCE

The following activities discussed in this section are means of identifying and prioritizing the potential problems with filter performance:

- Assessing filter hydraulic loading conditions;

- Assessing condition and placement of filter media;

- Assessing condition of support media and underdrains;

- Assessing backwash practices;

- Assessment of placing a filter back into service;

- Assessing rate-of-flow controllers and filter valve infrastructure; and,

- Assessing other plant processes, such as chemical feed rates, raw water quality changes, and turbidimeters.

You may not need to complete all of the activities listed in this section in order to identify the factors limiting filter performance. After the factors limiting filter performance have been identified, it may be possible to tie them to events in the filter profile. You should contact the State if you need assistance.
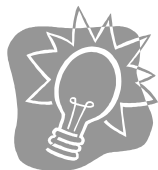
You should try to tie factors identified as limiting filter performance to the events on the filter profile.

5.4.1 Assessing Filter Hydraulic Loading Conditions

Topic	Description	Information	
		Actual	**Design**
Hydraulic Loading Conditions	Average operating flow (mgd or gpm)	960 gpm	896 gpm
	Peak instantaneous operating flow (mgd or gpm)	1,440 gpm	1,248 gpm
	Average hydraulic surface loading rate (gpm/ft^2)	3.0 gpm/ft^2	2.8 gpm/ft^2
	Peak hydraulic surface loading rate (gpm/ft^2)	4.5 gpm/ft^2	3.9 gpm/ft^2
	Changes in hydraulic loading rate (gpm/ft^2)	range from 2.0 to 4.5 gpm/ft^2	range from 2.0 to 3.9 gpm/ft^2

Excerpt from Table 5-1 containing sample data
Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

Filters may operate poorly when peak loading rates exceed filter design or when hydraulic loading rates change suddenly. Table 5-2 presents a summary of industry standard loading rates for various filters. **Filters may perform satisfactorily at loading rates other than those in Table 5-2; these values are general and provide a basis for evaluating excessive filter hydraulic loading.** State requirements may differ from acceptable industry loading rates and should be considered during the assessment.

Table 5-2. General Guide to Typical Filter Hydraulic Loading Rates

Filtration Type	Loading Rate
Sand Media	~2.0 gpm/ft^2
Dual/Mixed Media	~4.0 gpm/ft^2
Deep bed (anthracite > 60 in.)	~6.0 gpm/ft^2

You should check with the State on acceptable filter hydraulic loading rates.

For additional equations and mathematical reference see Appendix C.

Peak hydraulic loading rate should be calculated by dividing the peak flow to the filter (gpm) by the surface area of the filter (ft^2). Equation 5-1 demonstrates this method of calculating the peak hydraulic loading rate.

Equation 5-1 – Peak Hydraulic Loading Rate

Peak hydraulic loading rate = $\dfrac{\text{Peak filter flow (gpm)}}{\text{Filter area } (ft^2)}$

Since the filters can be most vulnerable during excessive loading rates, it is critical to determine the peak instantaneous flow that filters are experiencing and to minimize the occasions when filters are overloaded. You can identify the peak instantaneous operating flow rate by looking at operating records, operational practices, and flow control capability. A review of plant flow records can be misleading in determining the peak instantaneous operating flow. You can easily calculate average daily flow rate if the plant keeps track of total daily flow (total daily flow/minutes of plant operation). However, it is difficult to calculate instantaneous flow with total daily flow information. You should correctly identify the peak instantaneous operating conditions when reviewing flow data. If pumps are used in multiple combinations throughout the operational day, care should be taken to determine the actual peak loading on the filters during the day. As seen in Example 5-1, the peak hydraulic loading rate to the filters did not occur during peak plant flows. You may need to examine more than one operating scenario to correctly identify peak filter hydraulic loading rate.

You should check to see if the chemical pumps can operate at lower flow rates before decreasing flow rates through the plant.

<u>Example 5-1 – Calculating Peak Hydraulic Loading Rate</u>

A plant that operates 24 hours per day uses three 300-gpm pumps in various combinations throughout the year to meet system demand. The peak flow occurs for a 2-hour period each evening when all three pumps are used to fill on-site storage. Two pumps are used for the first hour and a half, while the third pump is used with the other two pumps only for the last 30 minutes of the 2-hour period. During that 30-minute period plant flow increases to 800 gpm. The peak instantaneous operating flow that goes onto the filters is 800 gpm.   The plant has two dual media filters (each 100 ft^2) and would have a peak hydraulic loading rate of 4.0 gpm/ft^2 at the 800 gpm peak flow.

Using Equation 5-1:

Peak hydraulic loading rate = Peak flow (gpm)/*Filter Surface Area* (ft^2)

$$= 800 \text{ gpm} / ((2 \text{ filters}) \text{ X } (100 \text{ ft}^2/\text{filter}))$$

$$= 800 \text{ gpm} / 200 \text{ ft}^2$$

$$= 4.0 \text{ gpm/ft}^2$$

This loading rate is within suggested rates. However, the system would want to avoid loading rates much higher than 4 gpm/ft^2 unless higher rates are allowed by design or recommended by the manufacturer and as long as the filtered water quality is acceptable.

For the same plant, the peak filter hydraulic loading rate could occur under a different set of circumstances. During the first hour and a half when the two pumps are on, one of the filters is taken off-line for backwashing. The peak flow is 540 gpm.

Peak hydraulic loading rate $= 540 \text{ gpm} / ((1 \text{ filter}) \text{ X } (100 \text{ ft}^2/\text{filter}))$

$$= 540 \text{ gpm} / 100 \text{ ft}^2$$

$$= 5.4 \text{ gpm/ft}^2$$

This loading rate to the filter is higher than the loading rate realized during the peak flow and exceeds the suggested range.

You may decide to calculate the loading rate to the filters if the system does not have flowmeters or if you want to check the flowmeters in the plant. Example 5-2 provides an example of how to perform this calculation.

Example 5-2 – Calculating Individual Filter Loading

A system has three filters, each with a surface area of 40 ft^2. A rise rate of 5 feet has been observed over a 1-hour period in the clearwell. The clearwell has a surface area of 200 ft^2. The system should calculate the flow to the clearwell and the hydraulic loading rate on each filter.

To calculate the flow, determine the volume of effluent discharging to the clearwell over a certain time period.

Flow to clearwell (gpm)= $\dfrac{\textit{Volume to clearwell (gal)}}{\textit{Time (minutes)}}$

$$= \dfrac{\textit{Rise in clearwell (ft) X Clearwell Surface Area (ft}^2\textit{) X 7.48 gal/ft}^3}{\textit{Time (minutes)}}$$

$$= \dfrac{\text{5ft X 200 ft}^2 \text{ X 7.48 gal/ft}^3}{\text{1 hour X (60 min/hr)}} = 125 \text{ gpm}$$

To calculate the hydraulic loading rate to each filter, divide the flow to the clearwell by the total filter surface area.

Hydraulic Loading to Each Filter (gpm/ft^2) = $\dfrac{\textit{Flow to clearwell (gpm)}}{\textit{\# of Filters X Surface Area of Each Filter (ft}^2)}$

$$= \dfrac{125 \text{ gpm}}{3 \text{ filters X 40 ft}^2}$$

Hydraulic Loading to Each Filter = **1 gpm/ft^2**

If only two filters are on-line, the hydraulic loading rate to each filter would be 1.6 gpm/ft^2.

This example assumes equal loading to each filter, and it provides an **estimate** of hydraulic loading to each filter. This example also assumes no flow is leaving the clearwell. If flow is leaving the clearwell, this flow should be added back in to estimate the filter hydraulic loading rate.

5.4.2 Assessing Condition & Placement of Filter Media

The activities associated with the assessment of filter media will probably require that the filter be off-line for a period of time. The system should plan accordingly to avoid plant upsets while the filter is off-line.

Topic	Description	Information	
		Actual	**Design**
Media Conditions	Depth, type, uniformity coefficient, and effective size	44 in., dual, gravity	48 in., dual, gravity
	Media 1	anthracite, 21 in.	anthracite, 24 in.
	Media 2 (if applicable)	sand, 23 in.	sand, 24 in.
	Media 3 (if applicable)	—	—
	Presence of mudballs, debris, excess chemical, cracking, worn media, media coating	mudballs, media coating	

Excerpt from Table 5-1 containing sample data. Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

Assessment of the condition and placement of the filter media is one of the steps you should take in identifying factors limiting performance of the filtration process. The presence of mudballs, surface cracking, or displaced media may often be attributed to excessive use of coagulant chemicals, inadequate backwashing, or a more serious problem related to the underdrain system. The assessment of the condition and placement of the filter media should include a physical inspection of the filter bed and a comparison of the actual media findings to the original specifications. The filter bed should be investigated for the following:

You should physically inspect the filter media and then compare the findings to the original media specifications.

- Irregularities in the surface;

- Surface cracking;

- Proper media depth;

- Presence of mudballs; and,

- Segregation of media.

Figure 5-8. Box Excavation Demonstration

Inspection

The inspection of the filter should consist of the following steps:

1) The filter inspection should begin by draining the filter.

2) As the filter is drained, you should observe the filter surface carefully. You should note areas where vortexing or ponding occurs. Areas of vortexing should be inspected for proper media and underdrain placement. Areas of ponding are a good indicator that the filter surface is not level.

3) The filter should be drained enough to allow for excavation of the media to assess the depths of each media type as well as each media interface (i.e., just below the anthracite/sand interface in a dual media filter).

4) Deeper excavation of the filter may be warranted if evidence suggests disrupted support gravels or an inadequate underdrain system (see Section 5.4.3).

5) **Care should be taken not to disrupt the support gravel or media while coring or probing.**

CAUTION

You should avoid disrupting the support gravel or media when coring or probing in the filter bed.

Media Inspection

If the filter is a pressure filter, coring the filter may be difficult or impossible. You should take any necessary safety precautions when entering a pressure filter since it may be considered a confined space. If the pressure filter has a viewing port the length of the filter media, you should periodically view the media for any signs of cracking, mudballs, media segregation, or any other changes in the media.

Filter media assessments may be conducted using a variety of coring devices (typically a 1½- to 2-inch thin-walled, galvanized pipe), a hand dig, a shovel, or if needed, a gross excavation technique. The gross excavation technique may be conducted using a plexiglass box like the ones shown in Figures 5-8 and 5-9. The box excavation consists of sinking a plexiglass box into the media and excavating inside the box down to the support media. The box excavation technique allows for visual observation of the media depths and interfaces after the excavation is completed.

Anyone who enters a filter box needs to be aware of confined space entry and lockout/tagout issues. Confined spaces may present safety hazards. Check with the local Occupational Safety and Health Association (OSHA) office for confined space entry requirements.

You should place pieces of plywood on the media before getting on the filters to support you and to avoid sinking into the media.

Additional Safety References include:
- AWWA Video *Safety First: Confined Spaces*
- AWWA Video Series *Safety Basics for Water Utilities*
- AWWA Manual *Safety Practices for Water Utilities (M3)*

For more information on media inspection, refer to *Filter Maintenance and Operations Guidance Manual* (American Water Works Association Research Foundation, 2002).

Figure 5-9. Box Used for Excavation

Media Placement

Whatever media excavation technique is used, you should note the depth of each media type, compare these depths to the original specifications, note the general condition of the media interface, and the presence of any mudballs (see Figure 5-10) or excess chemical. After the excavation is completed, the excavation team should make certain that the media is placed back in the excavation hole in the same sequence that it was removed.

Figure 5-10. Mudball from a Filter

Media Analyses

Coring methods offer the advantage of being able to apply the Floc Retention Analysis procedure (presented in Section 5.4.4), if conditions warrant. If media samples have been collected from the filter, you may want to consider having a sieve analysis conducted. A sieve analysis is recommended if it is suspected that the filter media size is wrong. The sieve analysis should be performed by a soils laboratory. The soils laboratory should determine the effective size and coefficient of uniformity for the different media; this will allow you to compare the laboratory results with filter media design specifications.

You may want to have a sieve analysis done on the media. Note that it may not be possible to complete a sieve analysis within the 14-day time frame required for a filter self-assessment.

You should make a list of your tools before entering the filter so that you can check them off as you leave.

Completing the Inspection

Before placing the filter back on-line after an inspection, consider these steps:

- **You should make sure all the tools used to inspect the filter have been collected and removed from the filter.** You should make a list of your tools before entering the filter so you can check them off as you leave.

- You should backwash the filter thoroughly before placing it back on-line. You should start the backwash very slowly to remove air, and you may want to add a disinfectant to the filter prior to backwash. You may also want to filter-to-waste after an inspection and before discharging to the clearwell.

5.4.3 Assessing Condition Of Support Media and Underdrains

Topic	Description	Information	
		Actual	**Design**
Support Media/Under-drain Conditions	Is the support media evenly placed (deviation <2 inches measured vertically) in the filter bed?	no	yes
	Type of underdrains	lateral	lateral
	Evidence of media in the clearwell or plenum	no	
	Evidence of boils during backwash	no	

Excerpt from Table 5-1 containing sample data. Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

Maintaining the integrity of the support gravels and underdrains (see Figure 5-11) is extremely important to the performance of a rapid rate granular filter. Disrupted or

Underdrains have a limited useful life and require periodic maintenance and inspection.

Uncontrolled air can disrupt support gravel.

CAUTION

Some underdrain systems do not require support gravel. Design documents should be reviewed to verify the presence or absence of support gravel.

unevenly placed support media can lead to rapid deterioration of the filtered water quality identified by quick turbidity breakthroughs and excessively short filter runs. Should disruption of the support media be significant, the impacted area of the filter may act as a "short-circuit" and may allow particulates and microbial pathogens to pass directly into the clearwell. Filter support gravels can become disrupted by various means including sudden violent backwash, excessive backwashing flow rates, entrained air in the filter, or uneven flow distribution during backwash. The number one cause of support gravel disruption is uncontrolled air. Also, air that accumulates during the filter run can disrupt gravel as it is released at the start of a backwash. This is why it is so important to start backwashes slowly at a low rate.

Figure 5-11. Underdrain System.

The condition of the support gravel can be assessed in three steps:

- **Step One –** As part of the normal backwash procedure, you should visually inspect the filter during a backwash to see if there is excessive air boiling or noticeable vortexing as the filter is drained. You should also look for any signs of pooling in low areas, which may indicate that the support gravel is not level.

- **Step Two** – You should "map" the filter using a steel or solid probe. This is the most common method of assessing the placement of filter support media. The mapping procedure involves a systematic probing through the filter media down to the support gravels of a drained filter at various locations in a grid-like manner. At each probe location, the depth of penetration into the filter should be measured against a

When probing a filter, be careful not to disrupt the support gravel or damage the filter media.

If the depth to the filter support gravel varies by more than 2 inches across the filter, further evaluation may be needed.
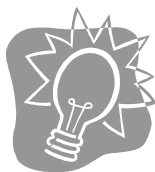
Some systems have used professional divers to inspect the clearwell for filter media. The advantage to using divers is that the clearwell will not need to be taken off-line and plant operations are only minimally disturbed.

fixed reference point such as the top of the wash water troughs. The distance from the fixed reference point to the top of the support gravel should not deviate vertically more than 2 inches. A grid map of the filter will help with tracking and recording measurements. Figure 5-12 shows an example of a grid. **Care should be taken during the filter probing not to disrupt the support gravel and to avoid damaging the filter media.**
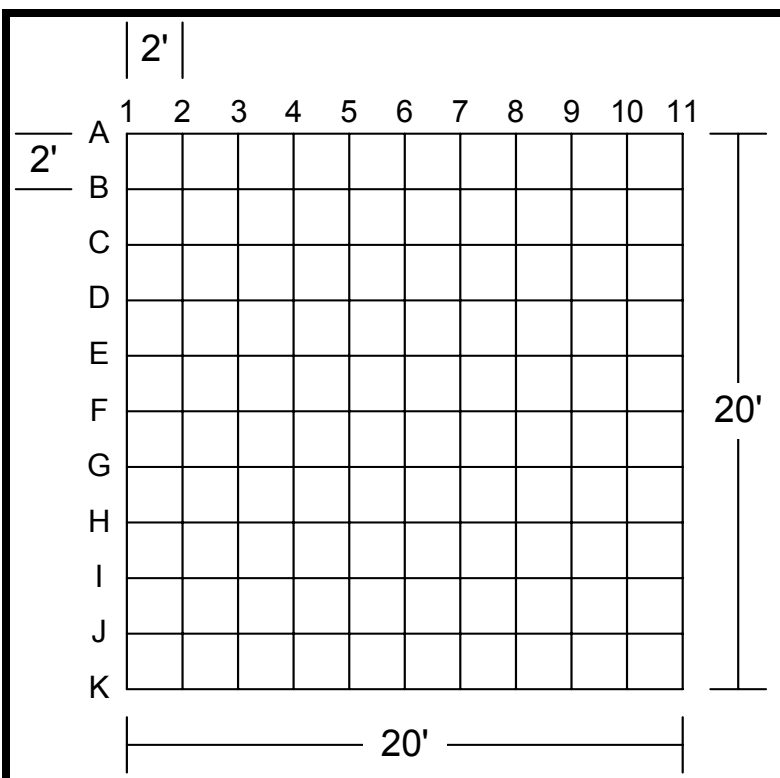
Figure 5-12. Example Grid of Filter Support Gravel.

In the example, shown in Figure 5-12, measurements of the support gravel are taken every 2 feet. A unique number is assigned to each sampling location and depth measurements are recorded at each location. If depths vary by more than two inches, the filter media, support gravel, and underdrain should be further evaluated.

- **Step Three** – You should determine whether filter media has ever been found in the clearwell. You should look for media in the clearwell and review recent clearwell maintenance records. Clearwell inspections should be conducted only following appropriate safety

procedures while minimizing negative impacts on necessary plant operations. A record of media in the clearwell may indicate a greater problem than just disrupted support gravels. The problem may be attributed to a severe disruption of the filter underdrain system. An in-depth assessment of the underdrains typically involves excavation of the entire filter bed.

You should use best professional judgment and seek additional guidance if undertaking an underdrain assessment, because it is outside the scope of a typical filter self-assessment.

5.4.4 Assessing Backwash Practices

Topic	Description	Information	
		Actual	**Design**
Backwash Conditions	Backwash initiation (headloss, turbidity/ particle counts, time)	turbidity	turbidity
	Sequence (surface wash, air scour, flow ramping, filter-to-waste)	1) surface wash 2) flow ramping 3) delayed start	1) surface wash 2) flow ramping 3) delayed start
	Duration (minutes) of each step	1) 3 min 2) 12 min 3) 30 min	1) 3 min 2) 12 min 3) 30 min
	Introduction of wash water (via pump, head tank, distribution system pressure)	pump	pump
	Backwash rate (gpm/ft^2) at each step	15 gpm/ft^2	15 gpm/ft^2
	Bed expansion (%)	14%	30%
	Dose of coagulants or polymers added to wash water	none	none
	Backwash termination (time, backwash turbidity, visual inspection, or other)	time	time
	Backwash SOP (exists and current)	available, current	available

Excerpt from Table 5-1 containing sample data. Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

Proper maintenance is essential to preserve the integrity of the filter as constructed. Filters that perform poorly as a result of filter media degradation or disruption of support gravel placement are often linked to problems with backwash. Both the flow rate and the duration of the backwash should be examined and adjusted if necessary. The optimal post-backwash condition for the filter varies for each treatment plant. Site-specific circumstances should be considered when making recommendations regarding filter backwash procedures. The focus should be on filter effluent water quality. Information to be collected, examined, and compared to filter specifications is contained in Table 5-1.

An assessment of the filter backwash procedure should include the following:

- Collection of general information related to the backwash (such as when to initiate backwash and length of backwash);

- Reviewing the backwash SOP;

- Visual inspection of a filter during backwash; and,

- Determination of the backwash rate and expansion of the filter media during the wash.

One indicator of filter performance is the ratio of water used for backwashing to the amount of water that was filtered during a typical filter run:

$$\text{Filter to backwash ratio} = \frac{\text{Backwash Water Volume}}{\text{Filtered Water Volume}} \times 100$$

The filter to backwash ratio should typically be between 3 and 6 percent for conventional filtration plants and 6 to 10 percent for direct filtration plants. This ratio may also vary with seasons, being lower in the summer and higher in the winter. If the ratio exceeds these ranges, filter performance is considered poor because frequent backwashing is being conducted. It may also indicate an inadequate level of pretreatment.

Backwash initiation can be based on:
1. Time
2. Headloss
3. Turbidity
4. Particle Counts

Surface washing is recommended during backwash whenever coagulants or polymer are used in pretreatment.

Initiation of Backwash

The backwash process is usually initiated when the head loss across the filter reaches a certain limit (established by the supplier or designer), when the filter effluent increases in turbidity or particle counts to an unacceptable level, or at a preset time limit determined by the system. You should verify that backwash is initiated in accordance with design specifications and established SOPs.

Backwash Sequence

The backwash process can consist of just backwashing with water, a combination of surface wash and backwash, ordinary air-scour, or simultaneous air and water wash. The backwash rate could also vary throughout the process. For example, the backwash rate could start at 10 gpm/ft^2 in combination with air scour or surface wash and then increase to 20 gpm/ft^2 after air scour or surface wash.

With the air-scouring wash, the violent boiling action typically occurs in the top 6 to 8 inches of the filter. In this case, mudballs that are present below this depth are not broken and will remain in the filter. Surface washing is recommended during backwash whenever coagulants or polymer are used in the pretreatment process. Surface washing should be done first, with backwash starting 2 to 3 minutes after surface washing begins (Kawamura, 2000). Operation of the surface wash during the backwash should be closely monitored because this can cause media loss in some filters, especially when the backwash rate is increased.

Identifying the Backwash Rate

Backwash rates should be adjusted to provide adequate cleaning of the filter media without washing media into the collection troughs or disrupting the support gravels. Backwash rates in gpm/ft^2 are calculated using backwash pump rates or backwash flows (see Equation 5-2).

If pump rates or flows are unavailable or suspect, backwash rates can be determined by performing a rise rate test of the filter. Periodic rise rate tests can also be used to verify the backwash flow measurement instruments. In the rise rate test, you can determine the amount of time it takes backwash water to rise a known distance in the filter bed. For this test, a metal

See Appendix C for more information and examples on calculating filter loading rates.

rod marked at 1-inch intervals (or similar device) is fixed in the filter to enable measurement of the distance that water rises during the wash. The rise rate test should be conducted so that measurements are taken without the interference of the wash water troughs in the rise volume calculation. Extreme care and great attention to safety should be followed while conducting the rise rate test. See Equations 5-2 and 5-3 and Example 5-3 for details on how to calculate the rise rate and backwash rate.

Equation 5-2 – Backwash Rate

$$\textit{Backwash Rate (gpm/ft}^2) = \frac{\textit{Backwash Flow (gpm)}}{\textit{Filter Surface Area (ft}^2)}$$

Equation 5-3 – Backwash Flow Using Rise Rate Test

$$\textit{Backwash Flow (gpm)} = \frac{\textit{Filter Surface Area (ft}^2) \; X \; \textit{Rise Distance (ft)} \; X \; \textit{7.48 gal/ft}^3}{\textit{Rise Time (minutes)}}$$

Example 5-3 – Determining the Backwash Rate from the Rise Rate

A filter having a 150 ft^2 surface area has a wash water rise of 10.7 inches in 20 seconds during the rise rate test. You should calculate the backwash rate.

First, you should determine the backwash flow in the filter using Equation 5-3.

$$\textit{Backwash Flow (gpm)} = \frac{150 \text{ ft}^2 \text{ X } 10.7 \text{ inches } (1 \text{ ft/12 inches) X } 7.48 \text{ gal/ft}^3}{20 \text{ seconds } (1 \text{ minute/60 seconds})}$$
$$= 3,000 \text{ gpm}$$

Second, you should determine the backwash rate using Equation 5-2.

$$\textit{Backwash Rate (gpm/ft}^2) = \frac{3,000 \text{ gpm}}{150 \text{ ft}^2} = 20 \text{ gpm/ft}^2$$

Bed Expansion

It is also extremely important to expand the filter media during the wash to maximize the removal of particles held in the filter or by the media. However, care should be taken to ensure that none of the media is lost through over-expansion, air scour, or surface wash. Bed expansion may be determined by measuring the distance from the top of the unexpanded media to a reference point (e.g., top of the filter wall) and from the top of the expanded media to the same reference point. Percent bed expansion may be determined by dividing the bed expansion by the total depth of expandable media (i.e., media depth less support gravels) and multiplied by 100 (see Equation 5-4 and Example 5-4). A proper backwash rate should expand the filter 20 to 25 percent, but expansion can be as high as 50 percent. Attention should be given to the influence of seasonal temperature changes on bed expansion during application of this procedure (see Appendix D). You should contact the manufacturer to determine the proper bed expansion for the media in the filters.

You should contact the manufacturer to determine the proper bed expansion for the media in the filters.

Equation 5-4 – Percent Bed Expansion

Before Backwash   During Backwash
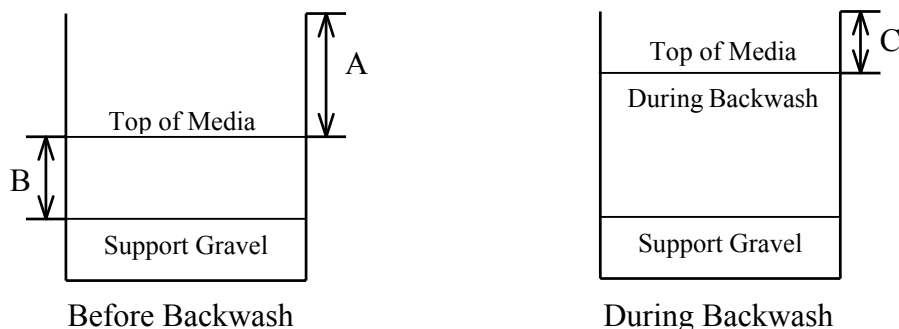
A = Depth to media as measured from top of sidewall before backwash.*

B = Media depth (less support gravel).*

C = Depth to expanded media as measured from top of sidewall during backwash.*

$$\text{Percent Bed Expansion} = \frac{A - C}{B} \times 100$$

*Make sure all measurements have the same units.

Example 5-4 – Evaluating Filter Backwash Bed Expansion Using a Secchi Disk

The backwashing practices for a filter with 30 inches of anthracite and sand is being evaluated. While at rest, the distance from the top of the filter sidewall to the top of the media is measured to be 41 inches. After the backwash has been started and the maximum backwash rate is achieved, a probe containing a white disk (referred to as a Secchi disk) is slowly lowered into the filter bed until anthracite is observed on the disk. The distance from the expanded media to the top of the filter sidewall is measured to be 34 inches. The resultant percent bed expansion would be 23 percent.

Depth to media as measured from top of sidewall before backwash = A = 41 inches
Depth to expanded media as measured from top of sidewall during backwash = C = 34 inches
Depth of filter media = B = 30 inches
Percent Bed Expansion = (41 inches – 34 inches) * 100 = 23%
                                 30 inches
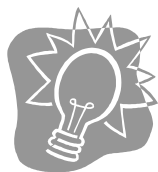
Bed expansion should not be measured during high surface wash agitation.

A variety of devices can be used to measure bed expansion. One common apparatus is a metal shaft with a white disk (called a "Secchi" disk) attached on one end (Figure 5-13). The disk unit is used by placing the disk on the unexpanded media prior to backwash and recording the length of the metal rod to the reference point. The disk unit is then removed and backwashing is initiated. After the backwash is allowed to reach its peak rate, the disk is lowered slowly into the backwashing filter until media is observed on the disk. The measurement of the expanded media is then recorded and the percent bed expansion may then be determined. The media expansion should be measured at several locations to see if expansion occurs over the full surface area of the filter. Uneven bed expansion throughout the filter could indicate uneven distribution of backwash water or an underdrain or support gravel problem. The key attribute of any method is that determination of the top of the expanded media be accurately characterized.

A flashlight or high-power cordless spotlight may be useful when using a Secchi disk to better identify when media is on the disk.

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Figure 5-13. Secchi Disk

When using a pipe organ apparatus to measure bed expansion, you should make sure that the apparatus is positioned where not all of the pipe segments will be filled.

Another device used to measure bed expansion is a steel measuring tape fitted along the shaft to a metal pole with an attached collection of plugged pipe segments of varying lengths. The pipes are arranged like a set of church organ pipes with each pipe one inch longer than the next (see Figure 5-14). The unit is solidly affixed, resting on the top of the media. During backwashing the expanded media fills each successive piece of pipe until the rise stops. Care should be taken to affix the pipe organ apparatus so it can easily be determined where bed expansion ended because if it is placed too low, all of the pipe segments will be filled with expanded media, making it

impossible to accurately determine media expansion. If this occurs, the apparatus should be emptied, affixed higher in the filter above the media and the bed expansion test repeated.

Figure 5-14. "Pipe Organ" Expansion

Backwash Effectiveness

A Floc Retention Analysis may be warranted if the filter is meeting backwash expansion and backwash rate guidelines, but still not achieving turbidity performance criteria (Kawamura, 2000). The Floc Retention Analysis procedure allows for an in-depth analysis of the effectiveness of backwash practices.

The Floc Retention Analysis procedure, sometimes referred to as the Sludge Retention Analysis procedure, can be used to determine the amount of particle retention occurring at each depth and area of the filter bed and the effectiveness of backwash procedures.

The Floc Retention Analysis can be performed using the following steps:

1. Completely drain the filter at the end of a filter run and let stand for 2-1/2 hours.

2. Mark a one-gallon plastic bag (best to use a waterproof marker) for each depth interval and collect four to eight samples at representative sites in the filter bed at the following depths: 0-2, 2-6, 6-12, 12-18, 18-24, 24-30, and 30-36 inches. If the filter is more than 36 inches deep, collect additional core samples in increments of 6 inches. Place the composite media samples from each

If a filter is meeting backwash guidelines but is not achieving turbidity performance criteria, a Floc Retention Analysis may need to be conducted.

depth in the appropriate one-gallon plastic bag. The core samples can be obtained using a thin-walled 1-1/2-inch galvanized pipe.

3. Prepare a 50 milliliter (mL) test sample from each of the sample bags by lightly tamping the core samples into a graduated cylinder. Transfer the 50 mL media sample to a large (500 mL) flask or beaker and add 100 mL of water. Swirl for 1 minute. Decant the turbid water from the sample into another beaker. Repeat this washing procedure with each sample four more times so that a total of 500 mL of water is used to wash out the sludge adhered to the media from each sample depth. Measure the turbidity of the 500 mL of wash water. Multiply the recorded turbidity by two so that the final tabulations for each depth will list the turbidity for 100 mL of sample instead of the 50 mL sample used. Record the turbidity results for each depth of the media.

4. Be sure to start the backwash cycle very slowly to remove air.

5. After the backwash is done, drain the filter completely.

6. Repeat Steps 2 and 3 in the same locations.

7. Backwash the filter and place it back in service. Be sure to start the backwash very slowly to remove air.

8. The results should then be plotted to determine the floc retention before and after backwash.

An ideal floc retention profile should show linear results with more particle retention at the top of the filter than at the bottom of the filter. Figures 5-15 and 5-16 show examples of Floc Retention Analysis plots. Figure 5-15 indicates that most particles are captured in the upper media of the filter and the backwash effectively cleaned the media at all depths. Figure 5-16 indicates that most particles are retained in the upper media and at the sand/anthracite interface. In addition, the backwash was not effective in cleaning the sand/anthracite interface.

Additional data on the filter media can be gathered, including effective size and uniformity coefficient of the media.

CAUTION

When backwashing a drained filter, be sure to start the backwash very slowly to remove air from the filter.
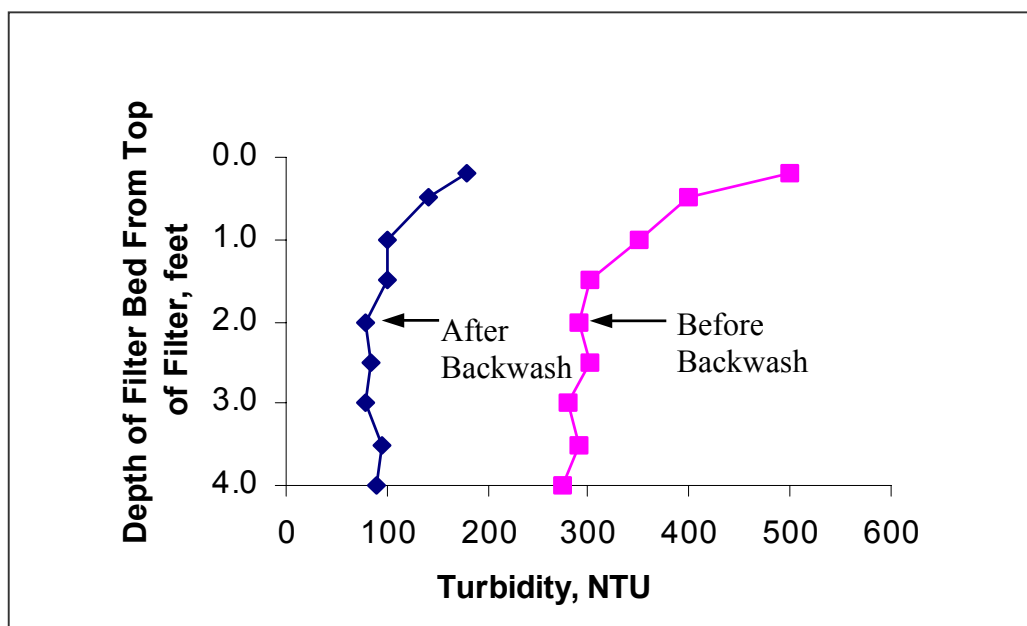
**Figure 5-15. Example of Floc Retention Analysis Results
for 4-foot Deep Mono Media Filter Bed**
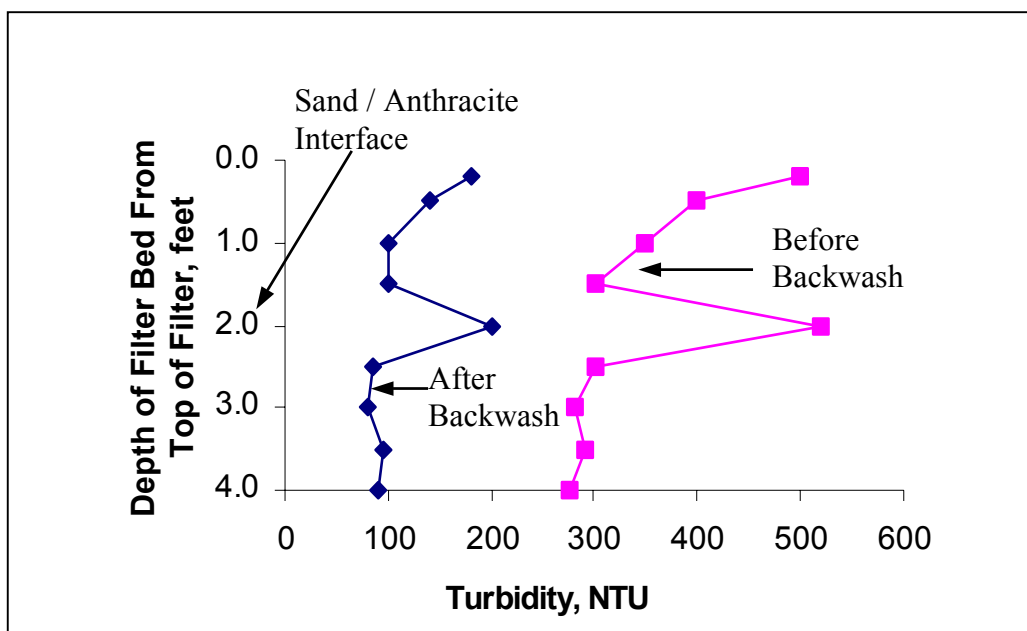
**Figure 5-16. Example of Floc Retention Analysis Results for
4-foot Deep Dual Media Filter Bed**

(Note increased particle retention at media interface)

You may need to vary the backwash rate with temperature changes because water properties vary with temperature.

Backwash Rate

You may want to consider varying the backwash rate as the water temperature varies, because water properties vary with temperature. Cold water is more viscous than warm water. Therefore, you should decrease the backwash rate for colder water and increase the backwash rate for warmer water. A guide for adjusting the backwash rates is available in Appendix D.

Terminating the Backwash

You should also evaluate criteria for terminating the backwash process. Termination of the backwash should be based on measured turbidity in the backwash water. Backwash samples can be obtained every 30 seconds or every minute and analyzed using a benchtop turbidimeter. A suggested guideline is that the backwash process should be terminated if the backwash turbidity is 10 to 15 NTU (Kawamura, 2000). Utilities should watch the backwash and observe water quality routinely.

A backwash SOP may help train new operators and improve operational consistency.

Backwash SOP

An adequate backwash SOP should describe specific steps regarding when to initiate backwash, how flows are increased or decreased during the wash, when to start and stop surface wash or air scour, and the duration of the wash. The SOP may help in training new operators and should improve operational consistency.

5.4.5 Assessment of Placing a Filter Back Into Service

Topic	Description	Information	
		Actual	**Design**
Placing a Filter Back into Service	Delayed start, slow start, polymer addition, or filter to waste	delayed start	delayed start

Excerpt from Table 5-1 containing sample data. Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

The methods used for placing a filter back into service after backwashing varies. The following methods are used in some water treatment plants:

- **Delayed start** - The delayed start consists of letting the filter rest for a period of time after backwashing and before placing the filter back into service. This practice has been found to reduce filter ripening times. The length of this delay varies, so the rest period should be determined by doing a study.

- **Slow start** - The slow start technique involves a gradual increase of flow through the filter until the desired hydraulic loading rate is achieved. This practice can reduce initial turbidity spikes but may require modification of the system or manual operation of the valve to control the feed rate to the filter.

- **Filter-to-waste** – Filter-to-waste is a common practice that allows filtered effluent to be sent to a part of the plant other than the clearwell after the filter goes back on-line. Once turbidity reaches an acceptable level, the filtered effluent is discharged to the clearwell. You should make sure that no cross connection exists between the filter effluent and the waste location.

- **Addition of a coagulant or filter aid during initial start-up of the filter or backwash** – You may also want to consider feeding a coagulant or filter aid during the initial start-up of the filter or during the last part of the backwash process. This option has been shown to reduce initial turbidity spikes.

Some plants use a combination of the techniques above to minimize filter turbidity spikes. Chapter 8 contains additional information on these techniques.

You should avoid placing a dirty filter (one that has not been backwashed) into service. This practice can result in very high turbidities and has the potential to pass pathogens into the finished water.

CAUTION

Avoid starting dirty filters!

5.4.6 Assessing Rate-Of-Flow Controllers and Filter Valve Infrastructure

Topic	Description	Information	
		Actual	**Design**
Rate-of-Flow Controllers and Filter Valves	Leaking valves	none	
	Malfunction rate of flow control valves	yes	
	Equal flow distribution to each filter	no	Yes

Excerpt from Table 5-1 containing sample data.
Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

The rate-of-flow controllers and ancillary valving related to the filter can have a significant impact on filter performance. Rapid hydraulic changes may cause filters to shed particles.

Maintaining and calibrating or verifying the accuracy of rate-of-flow controllers is an important part of minimizing hydraulic changes through the filter.

Improperly seated valves can leak and affect filter performance. All filter assessments should include an evaluation of all rate-of-flow controllers and filter valving.

Leaking Valves

One way to check for leaking effluent valves is to close the filter influent and effluent valves and observe the water level change in the filter. If the water level continues to drop with the valves closed, there may be a leaking effluent valve. If the water continues to rise, then there may be a leaking influent valve. The filter profile may be useful in determining if a leaking valve exists. Also, listening to the valves can help detect problems.

Flowmeters

If individual filter effluent totalizers are available, you should compare total daily effluent volumes for each filter. This process may help identify which filter is operating too high or too low compared to other filters. The problem may be a

poorly operating valve, a controller malfunction, or problems in the filter media.

Level Indicators and Speed Control Valves

If your plant is automated, it is critical to ensure that the instruments that govern filtration work properly.

5.4.7 Other Considerations

Topic	Description	Information	
		Actual	**Design**
Other Considerations	Chemical feed problems	no	
	Rapid changes in raw water quality	no	yes
	Turbidimeters (calibrated)	properly calibrated	—
	Other		

Excerpt from Table 5-1 containing sample data.
Blank copies of the full version of this table can be found in Table 5-1 and in Appendix B.

You may want to investigate other plant processes and data if any of the previously discussed areas do not seem to be causing the problem that triggered the filter self-assessment. You may want to examine chemical feed processes, raw water quality, and turbidimeters.

Chemical Feed Rates

Chemical feed processes and coagulation are important for proper floc formation. Poor floc formation can result in particles being passed through the filter. You may want to investigate chemical pumps and make sure the proper chemicals and feed rates are being used.

Raw Water Quality

A sudden change in raw water quality can cause particles to be passed through the filter, particularly if chemical feed rates cannot be adjusted in a timely manner. You may want to check raw water turbidity values and see if the turbidity spike was caused by a sudden increase in raw water turbidities.

See Section 7.2.2 for information on coagulation.

See Chapter 3 for more information on calibrating turbidimeters.

You should consult with the State to ensure agreement with your interpretation of the data.

Turbidimeters

You may want to calibrate and verify that turbidimeters are properly recording filtered water turbidimeter values. Turbidimeters can lose their accuracy over time and require calibration.

5.5 ASSESSMENT OF APPLICABILITY OF CORRECTIONS

After all the information on the filter has been collected on Table 5-1, you can start assessing factors that caused the turbidity levels that triggered the filter self-assessment. You may need to modify one or more of the filter features or operating conditions to address the event that triggered the filter self-assessment. In more severe instances, system-wide modifications may be needed. (These modifications would be identified through a CPE effort.) Table 5-1 may help identify areas of modification for the filter. Following are some examples of how corrections could be applied:

- Modifying filter run times.

- Creating or modifying a backwash SOP.

- Extending the filter backwash period to a time that results in acceptable filter turbidity levels.

- Replacing filter media if the filter media was determined to have reached its useful life.

- Adding more filters if filter loading rates were determined to be too high and additional filters are needed.

Many combinations of filter modifications exist, and you may have to try more than one modification to solve the problem.

5.6 PREPARATION OF THE REPORT

You should consult the State regarding the proper format and reporting requirements for the filter self-assessment report.

A system must prepare a report of the filter self-assessment. You should consult with the State on the proper format and State-specific reporting requirements. The report should include all the areas of the filter and filter operations examined and modifications that resulted in acceptable turbidity levels. If the problem cannot be identified within the timeframe allowed for completion of the self-assessment, the report should specify the anomalies that were observed and explain whether any corrective actions have yielded improvements. An example of a completed filter self-assessment report is included in Appendix E.

5.7 REFERENCES

1. AWWA. 1999. Water Quality and Treatment. Fifth Edition. McGraw-Hill, Inc. New York, New York.

2. Kawamura, S. 2000. Integrated Design of Water Treatment Facilities. John Wiley & Sons, Incorporated. New York, NY.

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6. COMPREHENSIVE PERFORMANCE EVALUATION

Detailed CPE procedures are not included in this guidance manual, but can be found in *Optimizing Water Treatment Plant Performance Using the Composite Correction Program Handbook* (EPA, 1998). This document can be obtained by calling the EPA Safe Drinking Water Hotline at 1-800-426-4791.

40 CFR Section 141.563(c)
If individual filter effluent turbidity exceeds 2.0 NTU in two consecutive recordings taken 15 minutes apart for two consecutive months, then a CPE must be conducted.

6.1 INTRODUCTION

The Comprehensive Performance Evaluation (CPE) is the evaluation phase of the Composite Correction Program (CCP). The goal of this chapter is to present a fundamental discussion of CPE concepts and provide an overview of what a system should expect when a CPE is completed.

Based on results of individual filter monitoring requirements in the LT1ESWTR, some systems may be required to arrange for a CPE. Specifically, systems must arrange for a CPE if any individual filter has a measured turbidity level greater than 2.0 NTU in two consecutive recordings taken 15 minutes apart for 2 months in a row (or if the combined filter effluent has a measured turbidity greater than 2.0 NTU in two consecutive recordings taken 15 minutes apart for 2 months in a row for systems with two filters that monitor combined filter effluent in lieu of individual filters). In addition, systems must report the filter number, the turbidity value, the date(s) on which the exceedance occurred, and the reason for the exceedance (if known) as part of the monthly report. The system must arrange for a CPE no later than 60 days following the day the filter exceeded 2.0 NTU in two consecutive 15-minute measurements for the second straight month. The CPE must be completed and submitted to the State no later than 120 days following the day the filter exceeded 2.0 NTU in two consecutive measurements for the second straight month. A separate CPE is not required if the State or State-approved third party has completed a CPE of the system within 12 months prior to the exceedance or the system and State are jointly participating in an ongoing Comprehensive Technical Assistance (CTA) project. The CPE must be conducted by the State or a third party approved by the State.

The CPE is a thorough review and analysis of a treatment plant's performance-based capabilities and associated administrative, operation, and maintenance practices. It is conducted to identify factors that may be adversely impacting a plant's capability to achieve compliance and emphasizes approaches that can be implemented without significant capital improvements. The CPE typically takes 3 to 5 days and is conducted by a team of two or more personnel. The major

Major Components of a CPE ➡️

components of the CPE process must include:

1. Assessment of plant performance;

2. Evaluation of major unit processes;

3. Identification and prioritization of factors limiting performance;

4. Assessment of applicability of the follow-up phase (i.e. comprehensive technical assistance); and,

5. Preparation of a CPE report..

At the core of the CPE is the assumption that if a filtration plant cannot achieve specific performance, there is a unique combination of interrelated factors with respect to the design, maintenance, administration, or operations of the filtration plant that are limiting its performance. The purpose of the CPE is to identify these factors and prioritize them according to their relative importance in preventing compliance or optimized performance. Once the factors are identified and prioritized, they can be corrected so that performance can be improved and compliance can be achieved.

During a CPE, the historic performance of the plant should be assessed with respect to pathogen removal and inactivation. The design, administration, and maintenance of the plant should be completely reviewed to determine if they properly support a plant capable of meeting specified filtration goals. If they are not supporting a capable plant, the root causes are identified as to how they are contributing to the performance problem. Operational practices should also be reviewed to determine whether operators have the necessary skills to achieve required performance and compliance when provided with a capable plant.

Figure 6-1 provides an overview of the CPE process.

For more information on the CPE process, refer to *Optimizing Water Treatment Plant Performance Using the Composite Correction Program Handbook* (EPA, 1998).

Location

Initial Activities

Off-Site

Kick-Off Meeting

Plant Tour

Data Collection Activities

| Administrative Data | Design Data | Operations Data | Maintenance Data | Performance Data |

Conduct Performance Assessment

Evaluate Major Unit Processes

On-Site

Perform Field Evaluations

Conduct Interviews

Identify and Prioritize Factors

Assess Applicability of Comprehensive Technical Assistance

Exit Meeting

CPE Report

Off-Site
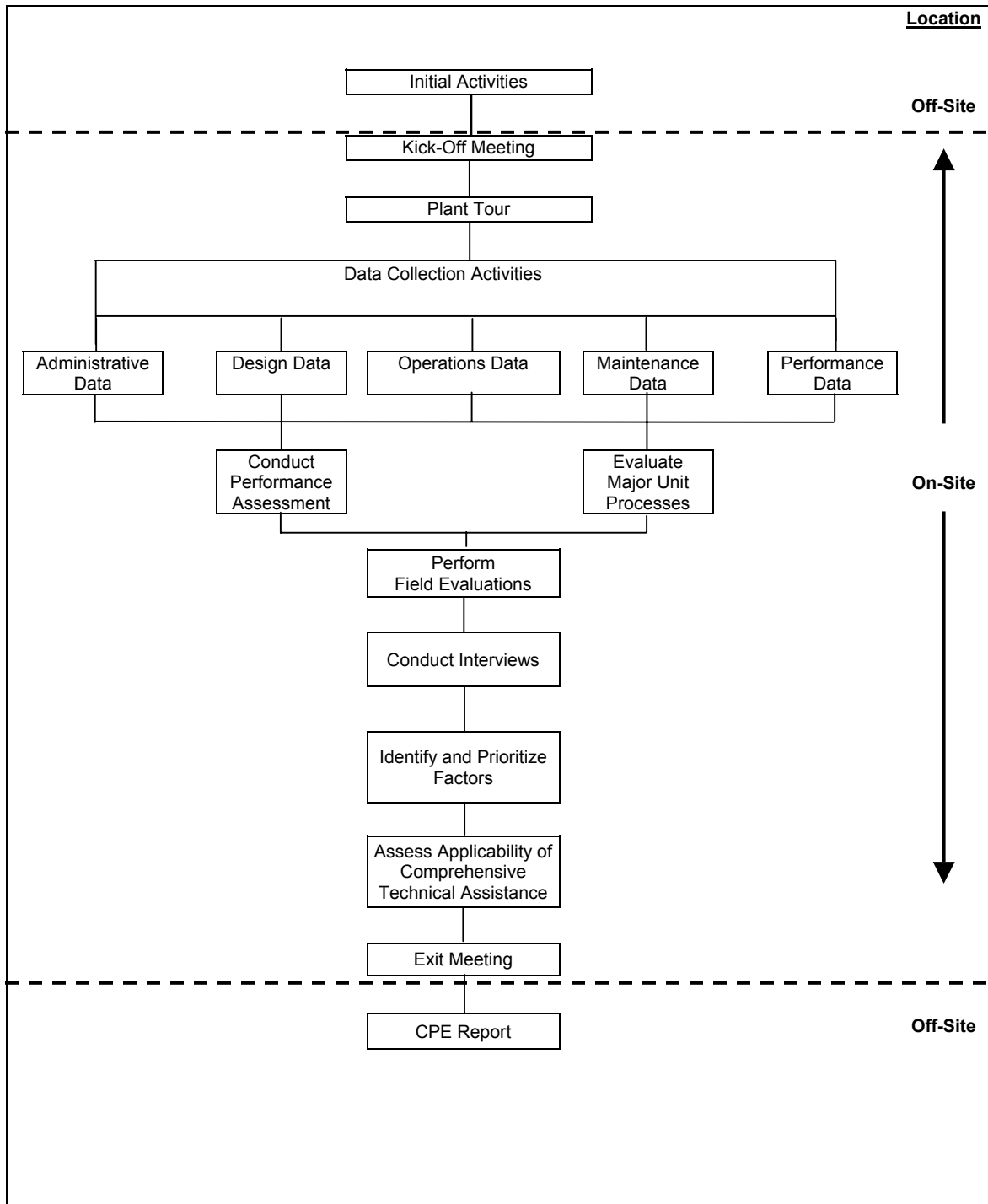
Figure 6-1. Typical Components of Activities During a CPE

6.2 REFERENCES

USEPA. 1998. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program (EPA 625-6-91-027). Washington, D.C.

7. TURBIDITY AND THE TREATMENT PROCESS

In this Chapter:
- The Treatment Process
- Recycle Streams

This chapter does not cover all aspects of water treatment. For more information, review the cited references.

7.1 TURBIDITY- WHY IS IT IMPORTANT?

Turbidity is the measure of how clear a liquid is and how much light is scattered by the sample (AWWA, 1990). It is measured in nephelometric turbidity units (NTU). Turbidity should not be confused with suspended solids, which expresses the weight of suspended material in the sample. There is no direct relationship between suspended solids and turbidity and exact comparisons between the two are difficult to make. Factors that contribute to turbidity in surface water are soil particles, organic matter, and pathogens (bacteria, viruses, and protozoa). Figure 7-1 provides a detailed overview of particle types and sizes found in surface water.

Turbidity in the water creates both aesthetic and health issues. Surface water treatment plants remove particles because they can cause objectionable appearances, tastes, and odors and can interfere with disinfection. Also, some pathogens, such as *Cryptosporidium*, which have been linked to waterborne diseases, are resistant to certain disinfectants. The most effective treatment for *Cryptosporidium* is filtration to ensure its removal. The LT1ESWTR requires filtered systems to achieve a 2-log removal of *Cryptosporidium* to reduce the possibility of waterborne diseases. Chapter 2 contains information on the turbidity monitoring requirements.
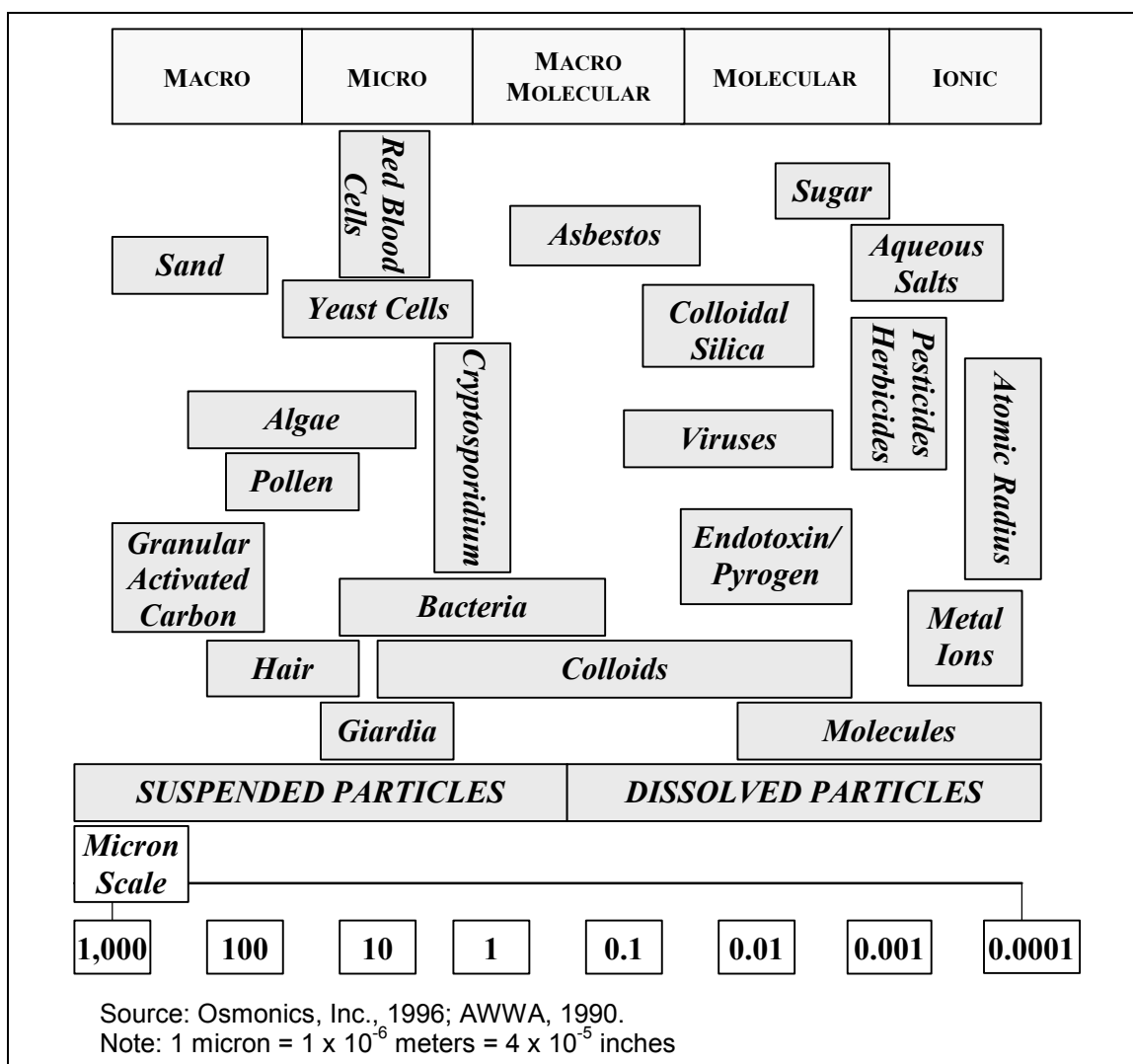
Figure 7-1. Particle Size Spectrum

7.2 THE TREATMENT PROCESS

Turbidity measurements are used to assess filter performance at a treatment plant. However, many other processes are involved in treating surface water. The surface water treatment process includes some or all of the following processes:

- Pre-sedimentation;

- Coagulation;

- Flocculation;

- Sedimentation and/or Clarification;

- Filtration; and,

- Disinfection.
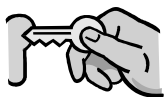
Producing consistently low effluent turbidity values ensures the public safety regarding drinking water.

Turbidity readings are usually taken of raw water, settled water, and filtered water to provide information for process control and to measure plant performance. Operators track raw water quality and adjust the treatment processes as necessary (such as coagulant and polymer feed rates). The two most common types of processes used to treat surface water are conventional treatment and direct filtration. Conventional treatment is typically used for source water that is high in turbidity, and direct filtration is more suitable for low-turbidity water. Figures 7-2 and 7-3 provide schematics for these two treatment processes.

In combination, all of the treatment processes of a surface water treatment plant provide a multiple barrier strategy. Microbial pathogens can be physically removed as particles through coagulation, flocculation, sedimentation, and filtration and are inactivated by disinfection. The level of protection achieved in a water system can be increased by optimizing the particle removal processes and by properly operating the disinfection processes (see Chapter 8). A brief discussion of each treatment process follows.
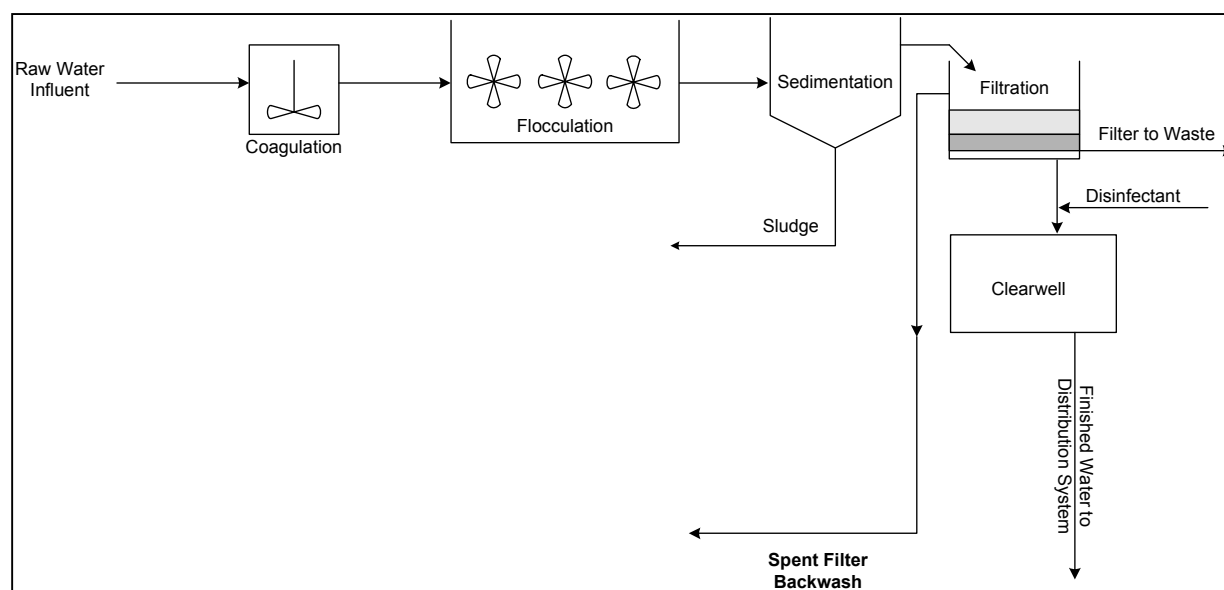
Figure 7-2. Conventional Treatment System
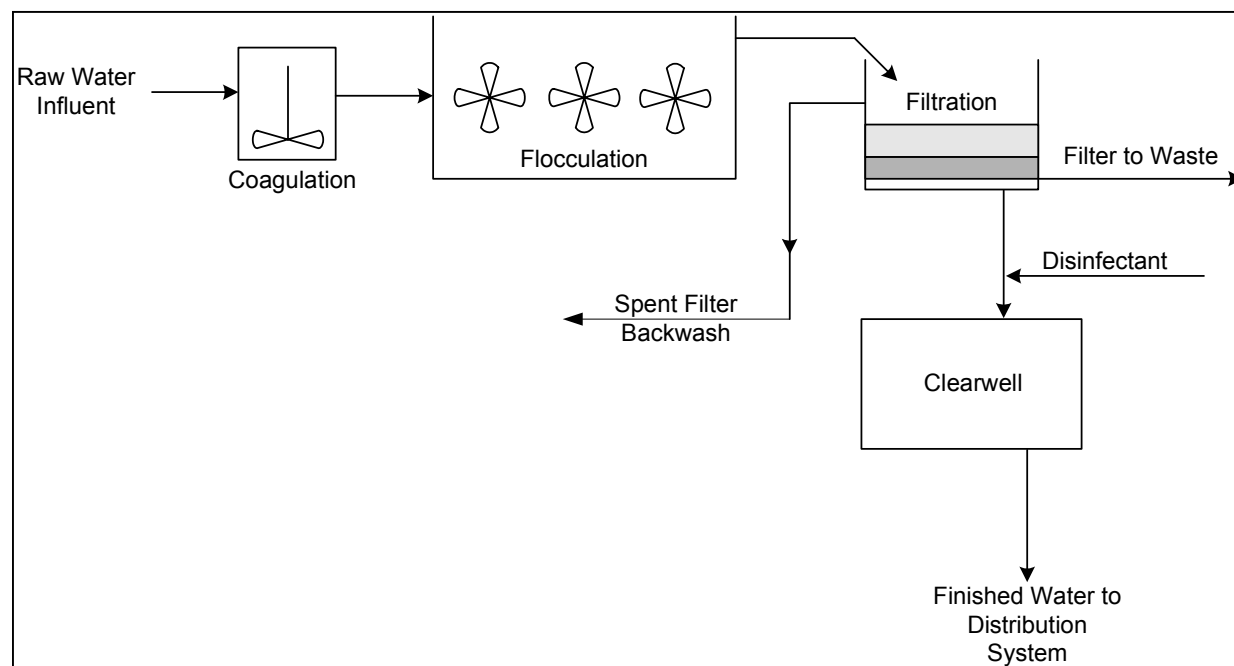
Figure 7-3. Direct Filtration System

7.2.1 Pre-Sedimentation

Not all systems use pre-sedimentation, but pre-sedimentation is often used when raw water turbidity is high or highly variable. Pre-sedimentation basins range in size, depending on the flow, and the water is sometimes pre-treated with a coagulant and/or a polymer prior to entering the pre-sedimentation basin (AWWA, 1999). The addition of coagulants and/or polymers at this point in the treatment process could be helpful if a system needs to reduce the natural organic matter entering the plant. Natural organic matter is a disinfection byproduct precursor, and if a system has high organic matter (measured as total organic carbon, or TOC), then pre-sedimentation could be beneficial for system compliance.

7.2.2 Coagulation

Coagulation is a process used for increasing the tendency of small particles in suspension to attach to one another and to attach to surfaces, such as the grains in the filter bed (AWWA, 1999). Typical coagulants used are discussed below:

- **Primary coagulants:** Primary coagulants are used to cause particles to become destabilized and begin to clump together (California State University, 1994). Examples of primary coagulants are metallic salts, such as aluminum sulfate (referred to as alum), ferric sulfate, and ferric chloride. Cationic polymers may also be used as primary coagulants.

- **Coagulant Aids and Enhanced Coagulants:** Coagulant aids and enhanced coagulants add density to slow-settling floc and help maintain floc formation (California State University, 1994). Organic polymers, such as polyaluminum hydroxychloride (PACl), are typically used to enhance coagulation in combination with a primary coagulant. The advantage of these organic polymers is that they have a high positive charge and are much more effective at small dosages. Even though they may be more expensive, a smaller amount may be needed, thereby saving money. Organic polymers also typically produce less sludge.

Mixing distributes the coagulant, which may actually temporarily increase the turbidity. Additional treatment processes (flocculation, sedimentation, and filtration) remove

40 CFR Section 141.2 defines coagulation as a process using coagulant chemicals and mixing by which colloidal and suspended materials are destabilized and agglomerated into flocs.

You should perform jar tests or pilot tests prior to modifying chemical feed practices. You should check with the State if considering modifications to chemical feed practices.

particles. Temperature, nature of turbidity, coagulant dose, mixing intensity, and pH affect the coagulation process.

Coagulants and Polymers

Chemicals commonly used in the coagulation process include aluminum or iron salts and organic polymers. The most common aluminum salt used for coagulation is aluminum sulfate, or alum. Alum may react in different ways to achieve coagulation. When used at relatively low doses (<5 mg/L), charge neutralization (destabilization) is believed to be the primary mechanism involved. At higher dosages, the primary coagulation mechanism tends to be entrapment. In this case, aluminum hydroxide ($Al(OH)_2$) precipitates forming a "sweep-floc" that tends to capture suspended solids as it settles out of suspension.

The pH range will vary from plant to plant. For instance, softening plants typically operate at higher pHs for effective softening.

The pH of the water plays an important role when alum is used for coagulation because the solubility of the aluminum species in water is pH dependent. If the pH of the water is between 4 and 5, alum is generally present in the form of positive ions (i.e., $Al(OH)^{2+}$, $Al_8(OH)^{4+}$, and Al^{3+}). However, optimum coagulation occurs when negatively charged forms of alum predominate, which occurs when the pH is between 6 and 8. When alum is used and charge neutralization is the primary coagulation mechanism, effective flash mixing is critical to the success of the process. When the primary mechanism is entrapment, effective flash mixing is less critical than flocculation.

You should be careful if alum is used at a low pH and then pH is suddenly increased later in the treatment process. This sudden increase in pH can result in floc settling out in subsequent treatment units, such as the clearwell.

Ferric chloride ($FeCl_3$) is the most common iron salt used to achieve coagulation. Its reactions in the coagulation process are similar to those of alum, but its relative solubility and pH range differ significantly from those of alum.

Both alum and ferric chloride can be used to generate inorganic polymeric coagulants. These coagulants are typically generated by partially neutralizing concentrated solutions of alum or ferric chloride with a base such as sodium hydroxide prior to their use in the coagulation process (AWWA and ASCE, 1990). The resulting inorganic polymers may have some advantages over alum or ferric chloride for turbidity removal in cold waters or in low-alkalinity waters.

Organic polymers tend to be large molecules composed of chains of smaller "monomer" groups (AWWA and ASCE, 1990). Because of their large size and charge characteristics, polymers can promote destabilization through bridging, charge neutralization, or both. Polymers are often used in conjunction with other coagulants such as alum or ferric chloride to optimize solids removal.

Rapid Mixing

Mixing distributes the coagulant chemicals throughout the water stream. When alum or ferric chloride is used to achieve destabilization through charge neutralization, it is extremely important that the coagulant chemical be distributed quickly and efficiently because the intermediate products of the coagulant reaction are the destabilizing agents. These intermediate species are short-lived and they must contact the solids particles in the water if destabilization is to be achieved. When other mechanisms are predominant in the coagulation process, or when organic polymers are being used as the coagulant chemical, immediate distribution of the coagulant chemical is not as critical and less-intense mixing may be acceptable, or even desirable. In some cases, excessive mixing may serve to break up coagulant molecules or floc particles, thereby reducing the effectiveness of subsequent solids removal processes.

The time needed to achieve efficient coagulation varies depending on the coagulation mechanism involved. When the mechanism is charge neutralization, the detention time needed may be one second or less. When the mechanism is sweep floc or entrapment, longer detention times on the order of 1 to 30 seconds may be appropriate (Kawumara, 2000; AWWA and ASCE, 1998; Hudson, 1981).

In general, the lower the coagulant dosage, the faster the mixing should occur because chemical reactions happen very quickly at low dosages. Rapid mixing disperses a coagulant through the raw water faster than the reaction takes place. When alum or ferric chloride are used in lower dosages (for charge destabilization; not sweep floc development), it is important to ensure that they mix very quickly with the raw water to be effective.

Mixing intensity is typically quantified with a number known as the "velocity gradient" or "G" value. The G value is a function of the power input into the mixing process and the volume of the reaction basin. Typical G values for coagulation mixing range from 300 to 8,000 sec^{-1} (Hudson, 1981).

Figure 7-4. Chemical Feed Pump (Alum)

<u>Effect on Turbidity</u>

Coagulation by itself does not reduce turbidity. In fact, turbidity may increase during the coagulation process due to additional insoluble compounds that are generated by chemical addition. The processes of flocculation, sedimentation, and filtration should be used with coagulation to reduce suspended solids and turbidity.

7.2.3 Flocculation

40 CFR Section 141.2 defines flocculation as a process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles through gentle stirring by hydraulic or mechanical means.

Flocculation is the "snowballing" of small particles into larger particles (called "floc") that can be more easily removed from water. Particles grow by colliding with other particles, and sticking together. Detention time is necessary for the formation of floc. The longer the detention time, the larger the floc. Temperature and pH also affect the flocculation process.

Flocculation is almost always used in the water treatment process after coagulation. Large particles are then more readily removed from the water in subsequent sedimentation and filtration processes.

<u>Slow Mixing</u>

Slow mixing is a key aspect of the flocculation process. In slow mixing, the water is stirred to encourage floc particles to clump together. Stirring too fast can break large particles apart, while stirring too slowly can prevent particles from clumping

When floc is stirred rapidly, "shearing" can occur. Shearing is when the floc itself breaks down into smaller polymer chains. It is extremely difficult to remove both the sheared flocculant and the particles.

enough. A wide variety of flocculation-mixing mechanisms have been used in water treatment. They include vertical shaft mechanical mixers, horizontal shaft mechanical mixers, and hydraulic mixing systems. Often, optimum performance is achieved by reducing the intensity of mixing as the water proceeds through flocculation (known as tapered or staged flocculation). Engineers have developed methods of determining appropriate stir rates, called "mixing intensity values," abbreviated as the letter "G." Generally, slow mixing should start out relatively fast (G values of 60 to 70 sec^{-1}) to promote clumping, and end up slower to prevent the larger clumps from breaking apart (G values of 10 to 30 sec^{-1}) (Kawamura, 2000). Many plants have found that changing mixers or mixing speed can improve floc characteristics, leading to lower clarified or settled turbidity before filtration.

Detention Time

The amount of time the water spends in the flocculation process is a key performance parameter. Adequate time should be provided to allow the generation of particles that are large enough to be removed efficiently in subsequent treatment processes. There is a wide range of optimum particle sizes, depending on what treatment processes are used downstream. For example, when sedimentation is used (conventional treatment), large floc particles are typically desirable because they readily settle out of suspension. If filtration directly follows the flocculation process (direct filtration), smaller floc particles may be the most desirable since they tend to be stronger and less susceptible to breaking up from the shear forces within the filters. Overall detention time in the flocculation process typically ranges from 10 to 30 minutes and is generally provided in several different basins or basin segments so the mixing intensity can be varied through the process.

Effect on Turbidity

As with coagulation, the purpose of flocculation is not to directly reduce turbidity or suspended solids, but to prepare the solids for subsequent removal. Flocculation reduces the number of suspended solids particles as smaller particles combine to form larger ones. This process may, or may not, result in reduced turbidity in the flocculation chamber.

40 CFR Section 141.2 defines sedimentation as a process for removal of solids before filtration by gravity or separation.
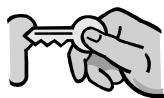
The efficiency of sedimentation directly affects sedimentation basin effluent turbidity.

7.2.4 Sedimentation and Clarification

Sedimentation is the process by which suspended particles are removed from the water by means of gravity or separation. In the sedimentation process, the water passes through a relatively quiet and still basin. In these conditions, the floc particles settle to the bottom of the basin, while "clear" water passes out of the basin over an effluent baffle or weir. Figure 7-5 illustrates a typical rectangular sedimentation basin. The solids collect on the basin bottom and are removed by a mechanical "sludge collection" device. As shown in Figure 7-6, the sludge collection device scrapes the solids (sludge) to a collection point within the basin from which it is pumped to disposal or to a sludge treatment process.

Sedimentation involves one or more basins, called "clarifiers." Clarifiers are relatively large open tanks that are either circular or rectangular in shape. In properly designed clarifiers, the velocity of the water is reduced so that gravity is the predominant force acting on the water/solids suspension. The key factor in this process is speed. The rate at which a floc particle drops out of the water has to be faster than the rate at which the water flows from the tank's inlet or slow mix end to its outlet or filtration end. The difference in specific gravity between the water and the particles causes the particles to settle to the bottom of the basin. Some plants have added baffles or weirs in their sedimentation basins to limit short-circuiting through the basins, promoting better settling.

Other forms of sedimentation used in the water industry are:

- Tube and plate settlers;

- Solids contact clarifiers, sludge blanket clarifiers, and contact clarifiers; and,

- Dissolved air flotation.

These forms of sedimentation typically allow for higher loading rates and/or improved particle removal than the basins illustrated in Figures 7-5 and 7-6. More information on these sedimentation processes is presented in the following sections.
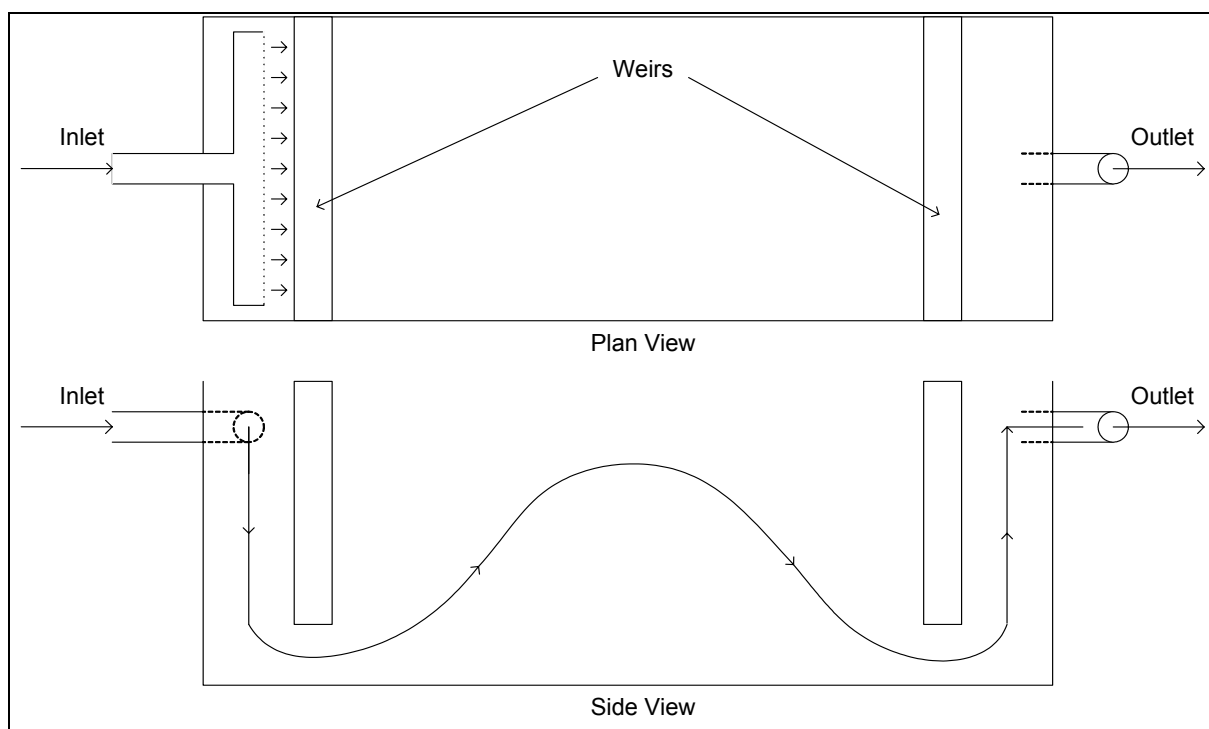
Figure 7-5. Rectangular Sedimentation Basin
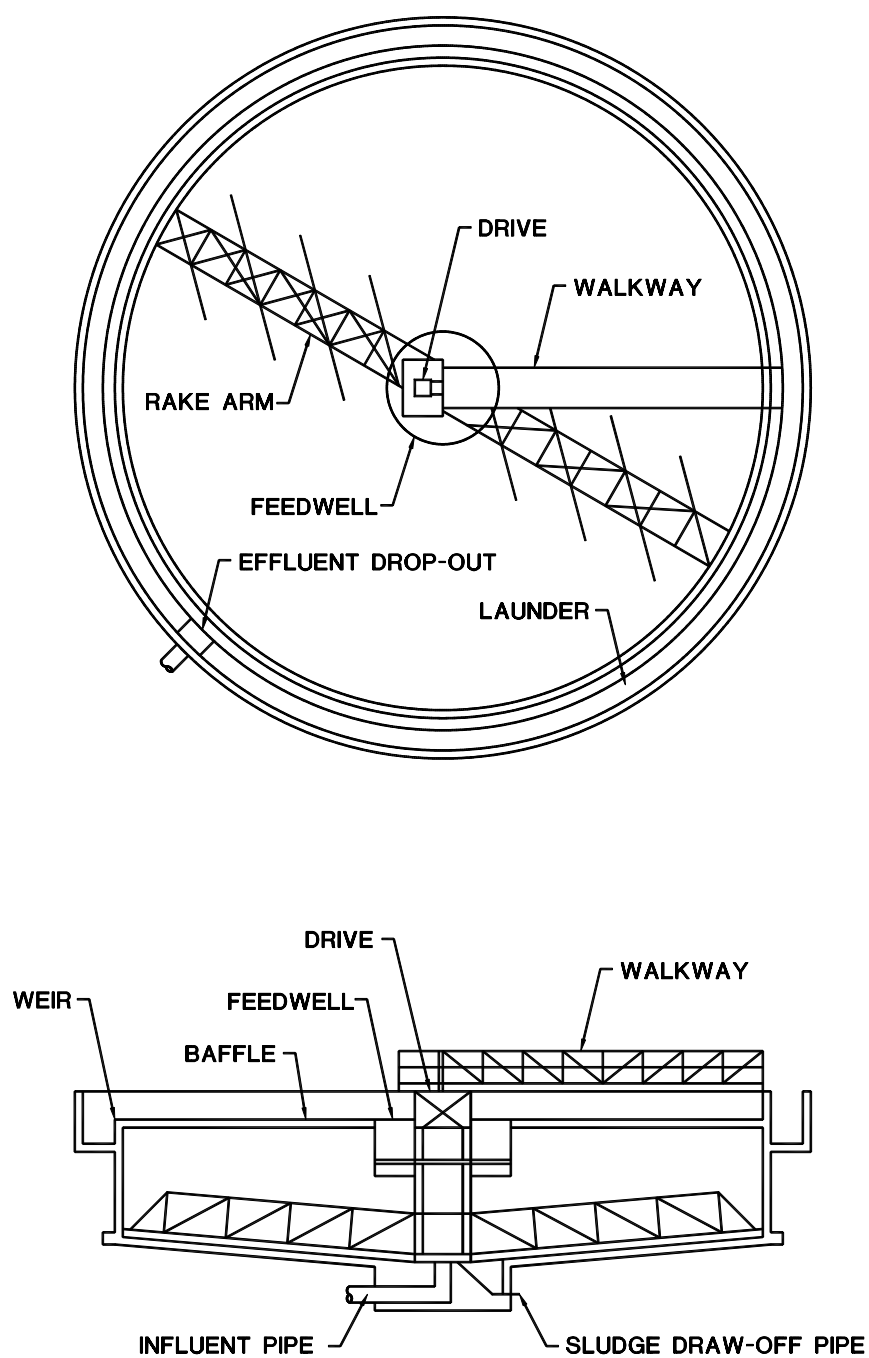
Source: AWWA and ASCE, 1990.

Figure 7-6. Circular Radial-Flow Clarifier

Tube and Plate Settlers

Inclined tubes and plates can be used in sedimentation basins to allow greater loading rates. This technology relies on the theory of reduced-depth sedimentation: particles need only settle to the surface of the tube or plate below for removal from the process flow. Generally, a space of two inches is provided between tube walls or plates to maximize settling efficiency. The typical angle of inclination is about 60 degrees, so that settled solids slide down to the bottom of the basin. Figure 7-7 illustrates a plate settler used for high-rate sedimentation.
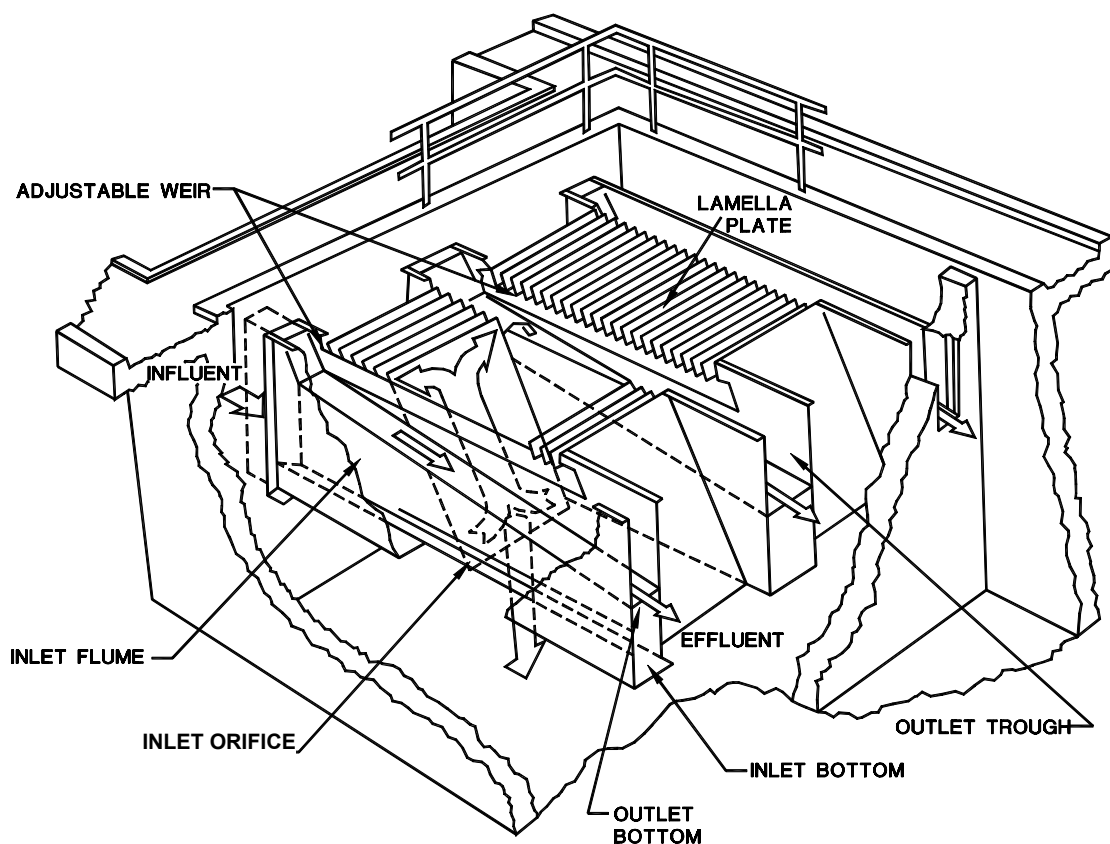
Source: AWWA and ASCE, 1998.

Figure 7-7. Plate Settlers Used for High-Rate Sedimentation

Solids Contact Clarifiers, Sludge Blanket Clarifiers, and Contact Clarifiers

Solids contact clarifiers represent an entirely different approach to high-rate clarification. They consist of a basin similar to that used for a conventional clarifier, but with a sludge recycle system to promote development of a dense sludge blanket that captures floc. There are numerous types of solids contact units on the market in the United States. These units are all similar in design in that they combine solids contact mixing, flocculation, solids-water-separation, and continuous removal of sludge in a single package-type basin. The recirculation rate of water and solids in solids contact units is critical to the units' effective operation. Too high a recirculation rate will cause the sludge blanket to lift and create increased loading to the filters.

- Accelator® solids contact clarifier

An Accelator® solids contact clarifier is shown in Figure 7-8. Raw water enters the primary mixing and reaction zone, where it receives the coagulant chemical. Coagulation and flocculation begin in this chamber in the presence of previously formed floc particles. These particles provide the nucleus of new floc particles. The resulting solids precipitant is pumped up into a secondary mixing and reaction zone. More gentle mix energy in this chamber allows completion of the flocculation process and separation of the solids. The mixture of solids and water flows down a draft tube. The downward flow starts the solids particles on a path down the hood to the sludge blanket at the bottom of the basin. Clear water flows up at a constantly reducing velocity that allows small particles to settle out. Other manufacturers of solids contact units may have flow patterns different than the Accelator® flow pattern.

- Sludge blanket clarifier

Sludge blanket clarifiers are a variation of solids contact units in which coagulated water flows up through a blanket of previously formed solids. As the small, coagulated particles enter the sludge blanket, contact with other particles in the blanket causes flocculation to occur. The floc grows in size and becomes part of the blanket. A blanket depth of several feet is required for efficient clarification (AWWA and ASCE, 1998).

- Contact clarifiers

Contact clarifiers (sometimes referred to as contact adsorption clarifiers) are designed to provide flocculation and clarification in a single process. These clarifiers consist of a basin filled with adsorption media, generally plastic or rock about the size

of pea gravel. As water passes through the media, hydraulic mixing promotes flocculation and the flocculated particles adhere to the surface of the media particles. The media is cleaned periodically using an air, or air and water, backwash process to remove the solids.
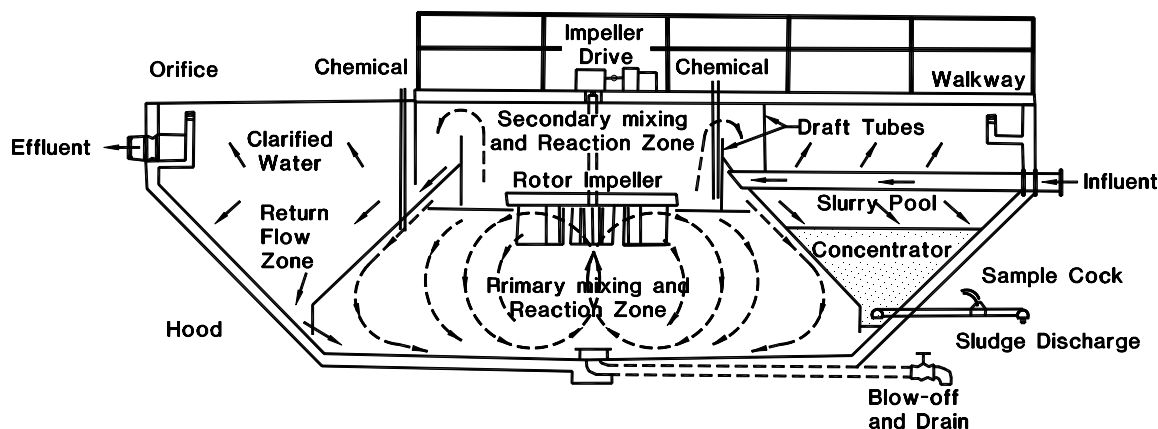
Source: AWWA and ASCE, 1998.

Figure 7-8. Accelator® Solids Contact Unit

Dissolved Air Flotation

Dissolved air flotation clarifiers bubble air into the flocculated water and cause the floc particles to float to the surface. Dissolved air flotation clarification allows for loading rates up to 10 times that of conventional clarifiers (AWWA and ASCE, 1998). Dissolved air flotation consists of saturating a side-stream with air at high pressure and then injecting it into a flotation tank to mix with incoming water. As the side-stream enters the flotation tank, the pressure drop releases the dissolved air. The air bubbles then rise, attaching to floc particles and creating a layer of sludge at the surface of the tank. The clarified water is collected near the bottom of the tank.

Effect on Turbidity

Reducing filter loads may extend filter run times and decrease the frequency of backwashes.

Sedimentation may remove suspended solids and reduce turbidity by about 50 to 90 percent, depending on the nature of the solids, the level of pretreatment provided, and the design of the clarifiers. Common values are in the 60 to 80 percent range (Hudson, 1981). A primary function of the sedimentation/ clarification process is to reduce the load of solids going to the

filters. Optimization of the clarification process will minimize solids loading on the filters and will contribute to enhanced filter performance and better overall treated water quality.

7.2.5 Filtration

Filtration removes particles and decreases turbidity. Operators should be familiar with the following terms that relate to filters:

40 CFR Section 141.2 defines filtration as a process for removing particulate matter from water by passage through porous media.

- **Backwashing:** A process used to clean the filter. In backwashing, an upward flow of water or a combination of upflowing water and air is pushed backwards through the filter. The flow washes out the load of particles in the filter. Backwashing is typically triggered at systems based on any one or a combination of three criteria: when the head loss across the filter reaches a certain limit (established by the supplier, design engineer, or operator), the filter effluent increases in turbidity (or particle counts) to an unacceptable level, or at a regular interval of time established by experience or by the supplier. Typical time limits for a filter run can range from 24 hours to 96 hours.

- **Breakthrough:** Towards the end of a filter run, the filter contains a large number of particles. When the filter carries too large a load, its removal ability decreases and increased numbers of particles pass through the filter. This is referred to as breakthrough. The result is decreasing filter effluent quality. Breakthrough can result due to excessive filter run time, poor chemical treatment, or other reasons. Backwashing is necessary to clean the filter.

Filter-to-waste is also referred to as rinse cycle or rewash cycle.

- **Filter-to-waste:** The process of discharging filtered water back to the plant headworks, raw water reservoir, sanitary sewer, or surface water. This occurs during the filter ripening period, the initial filter operating period after backwashing.

Several technologies exist to accomplish particle removal:

- Granular Bed Filters (i.e., slow sand, rapid granular bed, and pressure filters);

- Diatomaceous Earth (Precoat) Filters; and,

- Membranes.

Granular Bed Filters

Granular bed filters pass pre-treated water through a granular bed at varying rates. Flow is typically downward and can either be by gravity or pressure. As pre-treated water passes through the filter, solids are removed and accumulate within the filter. This clogging results in a gradual increase in head loss, which is one method used to determine when the filter needs backwashing. The materials commonly used in the filter (the filter media) are sand, crushed anthracite coal, granular activated carbon, or garnet. The filter can use just one of these materials or a combination of materials. When two materials are used, the filter is called a dual-media filter. If more than two materials are used, then the filter is classified as a multi-media filter. When more than one medium is used, the coarser material is placed at the top and the finer material is placed on the bottom. There are various types of granular bed filters, such as slow sand filters, rapid granular bed filters, and pressure filters.

Chemical pretreatment is important for proper particle removal in rapid granular bed filters and pressure filters. Chemical pretreatment is necessary to cause small particles to become larger particles. Larger particles are easier to remove in the processes preceding filtration and improve the transport mechanisms in filtration. In addition, chemical pretreatment enhances the attachment forces that help retain the particles in the filter (AWWA, 1999). On occasion, chemical pretreatment is used for slow sand filtration and is being studied further to allow slow sand filtration to be used for a wider range of source water characteristics.

Slow sand filters use a low application rate of water over a bed of fine sand. Application rates are typically between 0.016 gpm/ft^2 and 0.16 gpm/ft^2 (AWWA, 1999). Figure 7-9 depicts the general configuration of a slow sand filter. The filtered water is collected at the bottom of the filter in a gravel bed containing perforated pipe. A slow sand filter develops a biologically active layer called a schmutzdecke on the top that provides biological treatment of the water. Within the schmutzdecke, biological action breaks down some of the organic matter. Inert suspended particles may be physically strained out of the water. As the water moves through the filter, additional biological treatment and physical straining occurs. Slow sand filters are cleaned by removing the

Granular bed filters can be gravity or pressure driven and can consist of one or several types of media.

- Slow sand filter

Schmutzdecke is the biologically active layer in a slow sand filter.

schmutzdecke along with a small amount of sand. This process is called scraping. The scraping process can by repeated several times until the depth of the filter bed has decreased to about 16 to 20 inches. The filter material that is removed needs to be replaced.

- Rapid granular bed filter ➡ Rapid granular bed filters consist of one or more media. Water is applied at higher flow rates between 2 gpm/ft^2 and 10 gpm/ft^2. Rapid granular bed filters are equipped with an underdrain system that supports the filter media, collects filtered water, and evenly distributes backwash water and air scour (if air is used). The underdrain system sometimes consists of slotted pipe in a gravel bed. Figure 7-10 depicts a rapid granular bed filter.

SLOW SAND FILTER   FINISHED WATER STORAGE

SOURCE WATER
SUPERNATANT WATER DRAIN
FILTER TO WASTE AND BACKFILLING

HEAD SPACE
SUPERNATANT WATER
SCHMUTZDECKE
SAND MEDIA
SUPPORT GRAVEL
UNDERDRAIN

FLOW METER
EFFLUENT
Cl$_2$

VENT
TO DISTRIBUTION
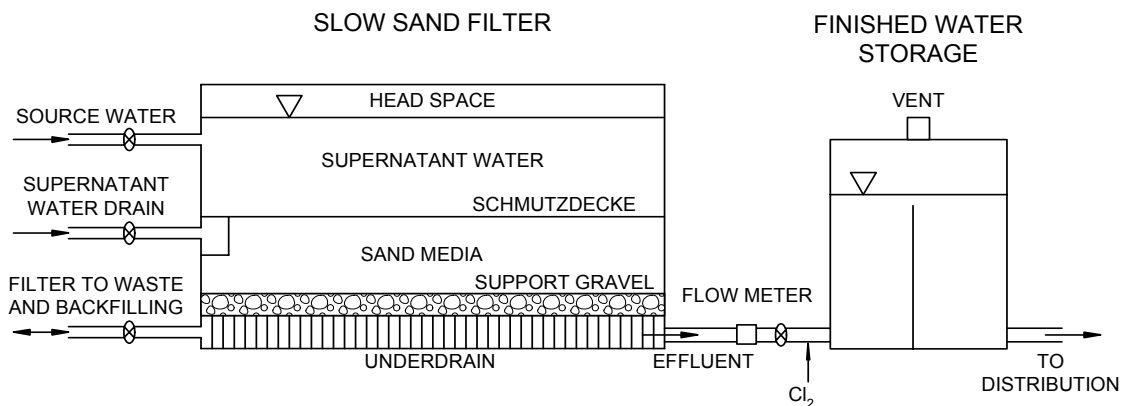
Source: AWWA and ASCE, 1998.

Figure 7-9. Typical Covered Slow Sand Filter Installation
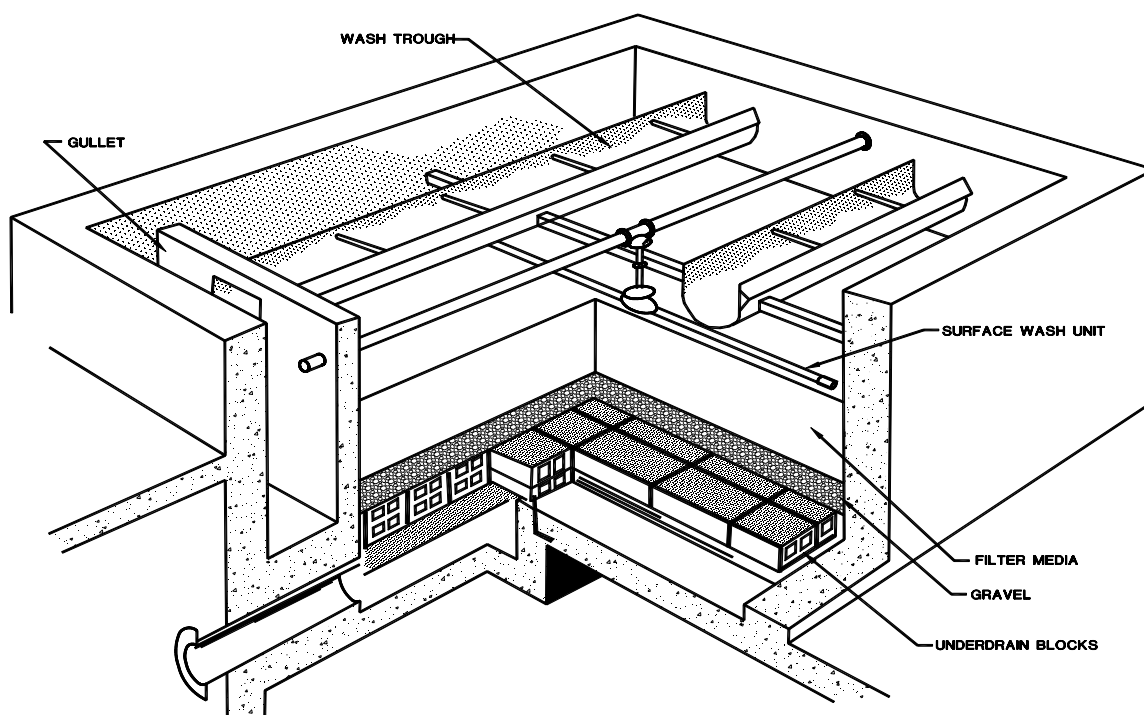
Source: AWWA and ASCE, 1998.

Figure 7-10. Typical Rapid Granular Bed

• Pressure filter

Pressure filters are similar in design to rapid granular bed filters, except that the water enters the filter under pressure and leaves the filter at a slightly reduced pressure (AWWA, 1999). Pressure filters are typically designed to operate in a downward flow manner. Figure 7-11 depicts a pressure filter that is designed to operate in a downward flow.
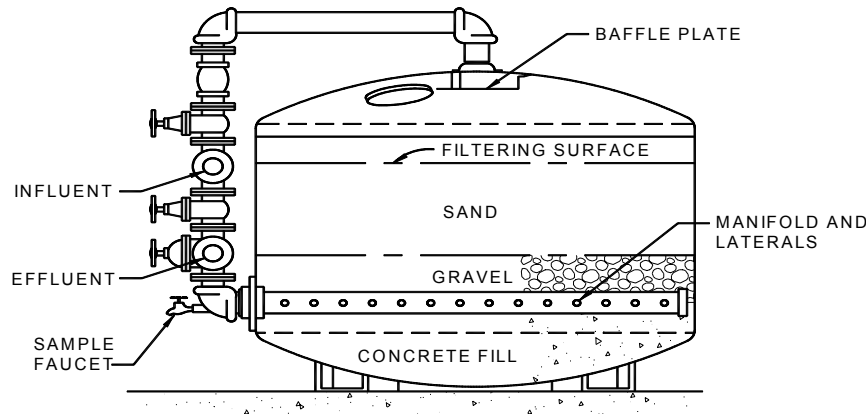
Source: AWWA and ASCE, 1990.

Figure 7-11. Cross-Section of a Typical Pressure Filter

Diatomaceous Earth (Precoat) Filters

In diatomaceous earth (precoat) filtration, the water to be filtered is passed through the filter medium that has been deposited (precoated) on a septum. Diatomaceous earth is the filter medium typically used for precoat filters. A septum is a permeable material that supports the filter medium. The septum is supported by a rigid structure called a filter element. Diatomaceous earth filters contain multiple filter elements and septa (AWWA, 1999). The filter operates either under a vacuum or pressure. The amount of filter medium used is proportional to the influent water feed during the filter run. When the pressure drop across the filter reaches a maximum level, the filter process is terminated. The filter material is removed and replaced with new media for the next filter cycle.

Membranes

Four basic classes of membrane technology are currently used in the water treatment industry: reverse osmosis, nanofiltration, ultrafiltration, and microfiltration. Figure 7-12 presents the typical pore size range and removal capabilities of these membrane process classes. Membranes have a distribution of pore sizes, which varies according to the membrane material and manufacturing process. When a pore size is stated, it can be presented as either nominal (i.e., the average pore size) or absolute (i.e., the maximum pore size) in terms of microns (μm). The removal capabilities of reverse osmosis and nanofiltration membranes are typically not stated in terms of pore size, but instead as a molecular weight cutoff representing the approximate size of the smallest molecule that can be removed by the membrane.

All of these membrane processes are effective at removing *Giardia, Cryptosporidium*, and most bacteria (provided the membrane has no leaks). The amount of removal depends on the type of membrane used. Reverse osmosis, nanofiltration, and ultrafiltration should also remove viruses, assuming there are no leaks in the membranes. Reverse osmosis and nanofiltration are capable of removing inorganic and organic contaminants, including DBP precursors (AWWA, 1999).

Membranes can be effective in decreasing the amount of DBPs formed:

- The removal of pathogens by membranes should reduce the amount of disinfectant required for inactivation and should result in lower finished water DBP concentrations; and,

- The removal of DBP precursors should result in lower finished water DBP concentrations (when reverse osmosis or nanofiltration is used).

It is important to remember that these membrane processes are physical barriers only, and they should be followed by disinfection to ensure inactivation of pathogens not removed by the membrane barrier, control of bacterial regrowth in downstream system plumbing, and an adequate distribution system residual. Membranes can also be used to achieve other treatment objectives. More information on membranes can be

Membranes can adequately remove several contaminants of concern from water. The contaminants removed depend on the pore size of the membrane used.

obtained from the *Membrane Filtration Guidance Manual* (EPA, 2003).

	Ionic Range	Molecular Range	Macro Molecular Range	Micro Particle Range	Macro Particle Range
Micron Scale	0.001　　　0.01		0.1　　　1.0	10	100　　　1000
Approximate Molecular Weight	100　　1000　10,000	100,000	500,000		
Typical Size Range of Selected Water Constituents	Dissolved Organics — Viruses — Salts		Bacteria — Colloids —	Cryptosporidium	Sand
Membrane Process*	Reverse Osmosis — Nanofiltration —	Ultrafiltration —	Microfiltration —	Particle Filtration	

* Particle Filtration is shown for reference only. It is not a membrane separation process.

Source: Kawamura, 2000.

Figure 7-12. Pressure-Driven Membrane Process Application Guide

Table 7-1 provides information on the typical pressure operating ranges for different types of pressure-driven membrane processes. Most pressure-driven membrane processes use either cellulose acetate or synthetic organic polymer membranes (AWWA and ASCE, 1998). Standard pressure membrane configurations include spiral wound membrane units and hollow fiber membrane units.

Table 7-1. Typical Feed Pressures for Pressure Driven Membrane Processes

Membrane Process	Typical Feed Pressure (psi)
Reverse Osmosis - Brackish Water Application	
Low Pressure	125 to 300
Standard Pressure	350 to 600
Seawater Application	800 to 1,200
Nanofiltration	50 to 150
Ultrafiltration	20 to 75
Microfiltration	15 to 30

Source: AWWA and ASCE, 1998.

Effects on Turbidity

When designed and operated properly, filters should be capable of complying with the LT1ESWTR turbidity requirements. Modifications to filter operation, such as decreasing the filter run time or modifying filter start-up procedures, may be necessary to achieve optimum filter performance. Chapter 5 provides information on the filter self-assessment process and includes suggestions for improving filter performance. Chapter 8 also contains case studies that address filter performance optimization.

7.2.6 Disinfection

Disinfection is required under the SWTR to ensure inactivation of pathogens. Disinfection is accomplished in several ways; the most common is a chlorine-based disinfectant. Chlorine is available in the gas, liquid, and solid form. Ozone and ultraviolet radiation (UV) are also used for disinfection. Sufficient contact time of the disinfectant with the treated water is important to obtain the proper inactivation of pathogens.

Turbidity removal is important to improve inactivation of pathogens. Removal of particles prior to disinfection offers the following advantages:

- Larger particles can shield pathogens. Pathogens are difficult to inactivate if the disinfectant cannot come into contact with the pathogen. Therefore, removing larger particles reduces shielding and may allow the disinfectant to come into contact with pathogens.

- The disinfectant demand is less when fewer particles are present.

More information on disinfection can be found in the *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual* (EPA, 2003).

- Generally, particle removal results in fewer DBPs by removing DBP precursors.

7.3 Recycle Streams

40 CFR Section 141.76
FBRR applies only to conventional and direct filtration systems that recycle spent filter backwash. The FBRR regulates three recycle streams: spent filter backwash water, thickener supernatant, and liquids from dewatering processes.

For more information on this rule, refer to the *FBRR Technical Guidance Manual* (EPA, 2003).

The Filter Backwash Recycling Rule (FBRR) regulates three recycle streams: spent filter backwash water, thickener supernatant, and liquids from dewatering processes. The objective of the FBRR is to improve the control of microbial pathogens, particularly *Cryptosporidium*, in public drinking water systems by helping to ensure that recycle practices do not compromise the treatment plants' capabilities to produce safe drinking water. The FBRR applies only to systems using conventional or direct filtration. It requires conventional and direct filtration plants to submit information to the State on their recycling practices. The system must also return recycle flows through the processes of its existing conventional or direct filtration system or at an alternate location approved by the State. The State will evaluate the system's recycling practice and may also require the system to modify its recycle practices. For more information on this rule, refer to the FBRR Technical Guidance Manual or the EPA Web site at http://www.epa.gov/safewater/filterbackwash.html.

7.4 REFERENCES

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8. TREATMENT OPTIMIZATION

Systems should consider treatment optimization prior to investigating major capital improvements to meet new turbidity requirements.

8.1 INTRODUCTION

While many systems already meet or will meet turbidity requirements prior to LT1ESWTR compliance deadlines, systems may choose to evaluate their treatment plants to determine what changes, if any, are needed to comply with the LT1ESWTR requirements. Optimizing treatment plants to improve effluent turbidity may be necessary for systems that are currently not performing as desired or are not in compliance. To optimize a facility, utilities should first evaluate the system and identify which processes could be modified. Although it is anticipated that compliance with the LT1ESWTR will generally be possible through adjustments to existing treatment processes, additional treatment processes or other treatment technologies or enhancements may be required in some cases. It is not anticipated that systems will need to make major capital improvements, but systems considering capital improvements in order to meet requirements of the LT1ESWTR should conduct an optimization evaluation similar to the Composite Correction Program (CCP) to assess the real need for construction.

The goals of treatment optimization are to:

- ✓ Provide safe drinking water and achieve compliance with required standards.

- ✓ Save money for the system without compromising safe drinking water.

These goals should be kept in mind when considering process modifications.

It is important to remember that the items listed in this chapter may not apply to all systems. Optimizing water treatment plants is a site-specific job. As such, this chapter does not try to provide one plan for optimizing a water treatment plant. It does highlight the areas which, in the experience of EPA and other water treatment professionals, most often can be improved to optimize water treatment and reduce water turbidity at water treatment plants.

8.2 TOOLS AVAILABLE FOR OPTIMIZATION

Three existing programs can be used to assist with optimization:

- Composite Correction Program
- Area-Wide Optimization Program
- Partnership for Safe Water

A thorough treatment plant evaluation and improvement program is the best way to ensure pathogen-free drinking water. With an emphasis on improved performance at minimal cost, optimization is an economical alternative for compliance with the turbidity requirements. Currently, three programs serve as excellent resources for systems wishing to follow a systematic and proven approach to optimizing water treatment plant performance. These are:

- CCP;
- Area-wide Optimization Program (AWOP); and,
- Partnership for Safe Water.

8.2.1 Composite Correction Program (CCP)

The CCP is a systematic, action-oriented approach that Federal or State regulators, consultants, or utility personnel can implement to improve performance of existing water treatment plants. The Comprehensive Performance Evaluation (CPE) phase of the CCP is described in greater detail in Chapter 6. EPA has developed a guidance manual, *Optimizing Water Treatment Plant Performance Using the Composite Correction Program Handbook* (EPA, 1998) that may be obtained by calling the EPA Safe Drinking Water Hotline at (800) 426-4791.

8.2.2 Area-Wide Optimization Program (AWOP)

EPA and State drinking water programs are responsible for oversight of surface water systems that represent a variety of source water characteristics, plant capabilities, and finished water quality supplied. An AWOP may be used to prioritize water systems for targeted regulatory oversight and possible technical assistance. An AWOP may be used to provide a process to identify systems with the highest public health risk and to implement proactive measures to improve performance of lower performing systems before they fall out of compliance with the LT1ESWTR. Participation in an AWOP is voluntary, however, States and systems that use AWOPs are realizing tangible benefits.

Overview of an AWOP

Implementation of an AWOP uses processes designed to optimize performance of existing particle removal and disinfection facilities of surface water treatment plants. The program facilitates water system regulatory compliance while building an awareness of the benefit of moving beyond regulatory requirements by optimizing treatment processes and thus increasing public health protection. AWOP activities focus on optimization of existing treatment processes using more effective process control, which will often limit the need for major capital expenditures.

AWOP enables States to target systems that may need additional assistance.

Under an AWOP, a State develops its own criteria to prioritize surface water systems relative to indicators of public health risk (e.g., turbidity removal performance, population served, violations). The State then uses the criteria to rank its surface water systems. This ranking provides a framework for effectively applying available resources and appropriate tools to the surface water treatment systems within a defined area. As an example, a State may choose its ranking criteria to assure it will focus on plants that have the greatest problems complying with the regulation. The process also includes tools that would assist the State to implement and document plant specific performance improvements, which allows for an assessment of the results of LT1ESWTR oversight activities.

Components of an AWOP

To establish an AWOP in a State, the drinking water program activities should be organized to support three interrelated functional areas of activities. These areas are:

- Status;

- Targeted Performance Improvement; and,

- Maintenance.

The intent of these activities is to create an ongoing, dynamic State implementation program that can respond to variations in surface water treatment plant performance requirements in a proactive and effective manner.
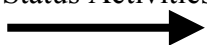
- Status Activities ➤ Status activities currently center around establishing turbidity performance goals that the State will pursue with its filtration plants. States work on developing their prioritization criteria they will use to rank and prioritize their systems. Once established, the State then uses turbidity data and other information obtained about the participating utilities to prioritize the plants based on their relative public health risk. This framework allows a State to monitor and assess these plants on a regular basis. Another benefit of the status activities is that it allows State staff to develop or strengthen relationships with the water utilities while encouraging them to pursue continuous performance improvement.

- Targeted Performance Improvement Activities ➤ The focus of the targeted performance improvement activities is to assess which of the various assistance tools is most appropriate to enhance the performance of each treatment plant based on their relative ranking (as determined by the status activities). In development of an AWOP, the States develop new tools as well as assess how their existing activities can be used to assist plants with achieving the AWOP performance goals for the long-term.

  A variety of tools are developed or used to improve performance at surface water plants. These can range from inspections to direct technical assistance. Options for an AWOP include, but are not limited to, enhanced inspections and surveys, CPEs, performance based training (PBT), and enforcement. States have the flexibility to incorporate the tools they find most appropriate given their skill level and resource constraints. Implementing an AWOP can help States utilize already existing information and organize it in a way to target oversight activities to achieve long-lasting improved performance on a system-by-system basis.

  Other sources of assistance that do not use State personnel can also be used. Systems may be encouraged to join national programs such as the Partnership for Safe Water. States may also choose to work with third-party technical assistance providers to make sure that their assistance complements the AWOP performance goals.

- Maintenance Activities

Maintenance activities center around taking lessons learned from implementation of the status and targeted performance improvement activities to integrate with or enhance other related State programs (e.g., design reviews, permitting, training activities, inspections, sanitary surveys). Any training of staff on new technical tools could also be included in this activity, as well as efforts to sustain capability and quality control of all AWOP activities.

8.2.3 Partnership for Safe Water

The Partnership for Safe Water is a voluntary cooperative effort of EPA, the American Water Works Association, other drinking water organizations, and over 186 surface water utilities representing 245 water treatment plants throughout the United States. Its goal is to provide a new measure of safety to millions of Americans by implementing common-sense prevention programs where legislation or regulation does not exist. The preventative measures are based on optimizing treatment plant performance and thus increasing protection against microbial contamination in America's drinking water supply. Information about the Partnership can be found at the AWWA Web site at http://www.awwa.org/partner1.htm or may be obtained by calling (303) 347-6169.

8.3 EVALUATING SYSTEM PROCESSES

Information presented in this section is site specific.

Systems should perform jar tests or pilot tests and consult the State prior to implementing any changes.

This section provides suggestions for evaluating the system to identify which processes to modify. The objective is to optimize plant performance to more easily meet all required drinking water standards. Optimizing the plant to meet the requirements for one rule (such as the LT1ESWTR) will not necessarily optimize water treatment for compliance with all standards. Certain technologies, especially those involving large financial expenditures, should be implemented only with appropriate engineering guidance. The following should be considered during the evaluation:

- ✓ Quality and type of source water;
- ✓ Turbidity of source water;
- ✓ Economies of scale and potential economic impact on the community being served;
- ✓ Treatment and waste disposal requirements; and,

When optimizing a facility for compliance with one rule, take care not to adversely affect compliance with another rule.

See Section 7.2.2 for more information on coagulation.

Poor coagulation techniques can result in high effluent turbidities.

Jar tests should be conducted to identify the optimal type and dosage of chemicals. *Operational Control of Coagulation and Filtration Processes*, AWWA M37, 1992 (available from AWWA, Denver, CO) is a good reference for jar testing.

✓ Future rules and requirements.

An engineering study should be conducted, if needed, to select a technically feasible and cost-effective method to meet the system's unique needs for improved filter effluent quality. Some situations may require more extensive water quality analyses or bench or pilot-scale testing. The engineering study may include preliminary designs and estimated capital, operating, and maintenance costs for full-scale treatment. Many States require a water system to seek approval for any major change to its treatment process. Consequently, a public water system should contact its regulatory agency before making major changes to the treatment plant.

8.3.1 Coagulation and Rapid Mixing

Coagulation is the process by which particles become destabilized and begin to clump together. Coagulation is an essential component in water treatment operations. Evaluation and optimization of the coagulation/rapid mixing step of the water treatment process includes a variety of aspects. Optimal coagulant dosages are critical to proper floc formation and filter performance. Maintaining the proper control of these chemicals can mean the difference between an optimized surface plant and a poorly run surface plant. Inadequate mixing of chemicals or their addition at inappropriate points in the treatment plant can also limit performance.

The raw water characteristics will affect the type and amount of chemicals used. Changes in raw water pH, temperature, alkalinity, total organic carbon, and turbidity will affect coagulation and, subsequently, filtration and finished water quality. Jar tests are an excellent way to determine the best type and amount of chemical (or combination of chemicals) to use for varying raw water characteristics. Appendix F provides information on jar testing. Also, documenting actual plant operations on a daily basis will give operators a resource for information about past treatment for various raw water conditions.

Table 8-1 provides some guidelines for selecting the proper chemical based on some raw water characteristics.

Table 8-1. Chemical Selection Guidelines Based on Raw Water Characteristics

Raw Water Parameter	Chemical Consideration
Alkalinity *Alkalinity is a measure of the ability to neutralize acid. Alkalinity levels are typically expressed as calcium carbonate (CaCO₃) in mg/L.*	Alkalinity influences how chemicals react with raw water. Too little alkalinity will result in poor floc formation, so the system may want to consider adding a supplemental source of alkalinity (such as lime, soda ash, or caustic soda). **Beware that these supplemental sources of alkalinity may raise the pH of the water, and further pH adjustment may be needed to obtain proper floc formation.** Systems should discuss this issue with a technical assistance provider or a chemical supplier. One rule of thumb is that alum consumes half as much alkalinity as ferric chloride.[1]
Alkalinity < 50 mg/L	This concentration of alkalinity is considered low, and acidic metallic salts, such as ferric chloride or alum, may not provide proper floc formation. Systems may want to consider a high basicity polymer, such as polyaluminum hydroxychloride (PACl), or an alum/polymer blend.[1]
Increase in total organic carbon	More coagulant is typically needed. Remember, organics influence the formation of disinfection byproducts and systems will need to comply with the Stage 1 Disinfection Byproduct Rule. A good resource is the EPA guidance manual *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual* (May 1999).
pH between 5.5 and 7.5	Optimum pH range for alum.[2]
pH between 5.0 and 8.5	Optimum pH range for ferric salts.[2]
pH > 8.5	Ferric salts might work or other high acidic coagulants[3].
Temperature < 5°C	Alum and ferric salts may not provide proper floc formation. May want to consider using PACl[1] or non-sulphated polyhydroxy aluminum chloride.[3]

[1] Lind and Ruehl, 1998.
[2] AWWA and ASCE, 1998.
[3] Greville, 1997.

Cost may be a consideration when selecting chemicals. The system should perform an economic analysis when comparing chemicals and not just compare unit cost. For instance, a polymer may cost more per unit than alum, but less polymer may be needed than alum. Therefore, the total cost for polymer may not be much different than the total cost for alum. The following issues may be evaluated as options to consider for treatment process enhancement.

Chemicals

An evaluation of the chemicals used in the treatment process can identify the appropriateness of the coagulation chemicals being used. A thorough understanding of coagulation chemistry is important, and changes to coagulation chemicals should not be made without careful consideration. The following items should be considered when evaluating chemicals and coagulation:

- What is the protocol for low-turbidity water? The primary coagulant should never be shut off, regardless of raw water turbidity.

- Are chemicals being dosed properly with regard to pH, alkalinity, and turbidity? Is dose selection based on frequent jar testing or other testing methods such as streaming current monitoring, zeta potential, or pilot filters? Relying exclusively on past practice may not be enough. The system may want to consider doing a jar test while the plant is running well to see how floc in the jar should look (see Appendix F for jar test information).

- Do standard operating procedures (SOPs) exist for coagulation controls? Systems should develop SOPs and establish a testing method that is suited to the plant and personnel. SOPs should be based on the consensus of all operators to ensure shared knowledge and experience. Also, all processes should be documented as they are performed so they may be reproduced in the future. An example SOP is provided in Appendix G.

- Are the correct chemicals being used? Is the best coagulant being used for the situation? Changing coagulant chemicals or adding coagulant aids may improve the settleability of the flocculated water and in

If a process change is made to the plant based on the results of jar testing, systems should remember to update the pertinent SOPs.

turn optimize performance. Coagulants may also be changed seasonally. The system should be carefully evaluated before full-scale plant changes of chemicals are made. If the system does change chemicals and needs an immediate response, the operator may need to purge the chemical feed line, particularly if the chemicals are far (several hundred feet or more) from the point of application.

- Does the pH need to be increased through supplemental alkalinity? Adding a supplemental source of alkalinity, such as lime or soda ash, may be necessary for proper floc formation. However, adding lime (or other alkali supplements) and iron- or aluminum-based coagulants at the same point can degrade turbidity removal performance. The coagulant works on the high pH lime, the same as it does with naturally occuring turbidity or alkalinity. Therefore, the addition of lime typically creates the demand for more ferric- or alum-based coagulant and the operator will probably add more coagulant in response to this demand. More coagulant can cause the pH to decrease, and more lime is typically added to compensate. Although finished water quality may be adequate when the raw water is stable, the plant pays a high cost in chemicals and sludge removal. This particular procedure is not foolproof and may not be effective at all when raw water characteristics change rapidly. One solution to this issue is to shift the feed line locations. Moving the coagulant line as far downstream as practicable from the lime addition point may allow the turbidity from the lime to fully dissolve. Placing the lime line well downstream of the coagulant addition point may allow for the coagulation of DBP precursors at a lower, more efficient pH before the lime addition elevates pH (Lind and Ruehl, 1998). Note that this mode of operation will not work for lime softening plants.

- Do operators have the ability to respond to varying water quality conditions by adjusting coagulation controls? Systems should provide operators with learning opportunities so that they are able to react to unusual situations quickly and appropriately. Heavy rains or lake turnover may happen rarely, but noting indicators of these events will help with planning. For example, a sudden drop in pH may occur prior to the

This practice is not recommended for lime softening plants.

Overdosing chemicals can be just as detrimental as under dosing. More is not always better.

You should check with the State prior to modifying chemical feed processes.

first heavy rain reaching the intake. Systems should use this as a trigger to change the coagulant dosage.

- Are chemicals used before manufacturer recommended expiration or use-by dates? Does the chemical supplier operate an ISO 9000 production facility and provide quality certification? Chemical purity is important in all treatment systems.

- Are chemicals being added in the correct order? The order of chemical addition is very important, because certain chemicals interfere with others. Jar tests should be used to develop optimal sequences. The system may also want to consider changing the location of chemical feed points. For instance, some utilities have found that optimum water quality was achieved when a coagulant was fed in raw water and a polymer was fed prior to filtration.

- Is the chemical feed system operating properly? Operators should consider checking the accuracy of chemical feed systems at least once daily or once per shift. The system may want to install calibration columns on chemical feed lines to verify proper dosage or provide some other form of calibration. Systems should not set the chemical feed pumps to operate at maximum stroke and feed rates, which can damage the pumps.

- Are chemicals properly mixed, particularly chemicals that are diluted? The system may want to consider an automatic mixer in the chemical tank to provide thorough mixing.

Figure 8-1. Polymer Feed Pump

Feed Systems

Feed systems are another important aspect of the coagulation step in typical treatment processes. Figure 8-1 shows an example of a polymer feed pump. Feed systems deliver coagulants into the treatment system at rates necessary for optimal performance. The following aspects of feed systems should be evaluated:

- Is redundancy a consideration? Redundancy should be built into the feed systems so that proper feeding of chemicals can be maintained if primary systems fail or malfunction.

- Do chemical feed pumps have sufficient dosage range? Feed systems should be sized so that chemical dosages can be changed to meet varying conditions.

- Are chemical feed systems and solution piping checked regularly? Preventive maintenance is critical for avoiding process upsets due to equipment breakdown. Coagulant lines should be flushed out frequently to prevent buildup. Where possible, chemical feed lines should be easy to take apart for quick replacement or simpler maintenance.

- Is a diaphragm pump used? A continuous pump allows coagulants to be added in a way that avoids pulsed flow patterns.

Due to the consistency of chemicals, systems with polymer pumps should perform preventive maintenance such as periodically moving hoses located in peristaltic pump heads or lubricating pump motors.

Systems should check feed rates and calibrate pumps as necessary.

- Does the plant stock repair parts for all critical equipment? Repair parts with a long lead-time for delivery should be reordered as soon as possible after removal from inventory.

Satisfactory Dispersal/Application Points

Ccoagulation and mixing also depends on satisfactory dispersal of coagulation chemicals and appropriate application points. Coagulants should be well-dispersed so that optimal coagulation may occur. Enough feed points should be used so chemicals are able to mix completely. The system should evaluate the following items:

- Is dispersion taking place? Coagulation reactions occur rapidly, probably in less than 1 second. When injecting at hydraulic jumps, weirs, or flumes, the coagulant should be distributed uniformly across the width of the flow.

- Where are coagulants being added? Generally, metal salts should be introduced at the point of maximum energy input. Low-molecular weight cationic polymers can be fed with metal salts at the rapid mix or at second stage mixing following the metal salt. High-molecular weight nonionic/anionic floc/filter aids should be introduced to the process stream at a point of gentle mixing. Most polymer feed solutions should be provided with a "cure time" or "aged" before use. Use of an inline blender with carrier water aids in further dispersal at application. Most polymers have specific preparation instructions and should not be added directly in the raw, concentrated form in which they are received.

- Is rapid mixing equipment checked frequently? Systems should check the condition of equipment and ensure that baffling provides for adequate, even flow.

8.3.2 Flocculation

Flocculation is the next step in most treatment plants (in-line filtration plants being the exception). It is a time-dependent process that directly affects clarification efficiency by providing multiple opportunities for particles suspended in water to collide through gentle and prolonged agitation. The

Stocking spare parts for pumps, tubing, etc. can save time and money.

See Section 7.2.3 for more information on flocculation.

process generally takes place in a basin equipped with a mixer that provides agitation. This agitation should be thorough enough to encourage inter-particle contact, but gentle enough to prevent disintegration of existing flocculated particles. Several issues regarding flocculation should be evaluated by utilities to ensure optimal operation of flocculation basins.

Flocculation Mixing and Time

Proper flocculation typically requires long, gentle mixing. Mixing energy should be high enough to bring coagulated particles constantly into contact with each other, but not so high it breaks up those particles already flocculated. The system should consider evaluating:

- How many stages are present in the flocculation system? Three or four are ideal to create plug flow conditions and allow desired floc formation.

- Is the mixing adequate to form desired floc particles? The system should consider decreasing the mixing rate for each subsequent stage. "G" values should be variable through the various stages from 70 sec^{-1} to 10 sec^{-1}.

- Are mechanical mixers functioning properly? Are flocculator paddles rotating at the correct speed or rates?

- If flow is split between two flocculators, are they mixing at the same speed and "G" value?

Flocculator Inlets and Outlets

Short-circuiting occurs when water bypasses the normal flow path through the basin and reaches the outlet in less than the normal detention time. Inlet and outlet turbulence is sometimes the source of floc-destructive energy and short-circuiting in flocculation basins. The system should evaluate the following:

- Do basin outlet conditions prevent the break-up of formed floc particles? Basin outlets should avoid floc breakup. Port velocities should be less than 0.5 feet per second (fps).

For more information on "G" values, see Section 7.2.3.

- Do inlet conditions prevent the breakup of formed floc particles? Inlet diffusers may improve the uniformity of the distribution of incoming water. Secondary entry baffles across inlets to basins may impart headloss for uniform water entry.

- What size are the conduits between the rapid mix basin and the flocculation basin? Larger connecting conduits help reduce turbulence which may otherwise upset floc.

Flocculator Basin Circulation

Baffles are used in flocculation basins to direct the movement of water through the basin. Baffling near the basin inlet and outlet improves basin hydraulics and achieves more uniform flow patterns. Systems should consider the following items when evaluating flocculation:

- Is current baffling adequate? Can baffling be added to improve performance, or does existing baffling require repair? Serpentine baffling is more effective than over/under because it provides for slower flow conditions and more time for floc formation. Baffling should prevent short-circuiting and promote plug flow conditions.

- If the system uses solids contact units (SCUs), it may want to evaluate the recirculation rate of water through primary and secondary reaction zones, sludge blanket depth and percent solids, and raw water flow rate. Sudden changes in raw water flow rate may upset the sludge blanket and cause sludge carry-over to the effluent collectors. There are several types of SCUs, and each has unique flow patterns and sludge blanket requirements. Therefore, the system should consult the SCU operations manual for proper operation and troubleshooting of performance problems.

Systems should check that the proper detention time is achieved in all flocculation basins under all flow conditions.

See Section 7.2.4 for more information on sedimentation.

8.3.3 Sedimentation

Sedimentation is the next step in conventional filtration plants. (Direct filtration plants omit this step.) The purpose of sedimentation is to enhance the filtration process by removing particulates. In sedimentation, water flows through the basin slowly enough to permit particles to settle to the bottom before the water exits the basin. The system should consider the following items when evaluating sedimentation basins:

- Conducting a tracer study in the sedimentation basin. Often, very simple design changes can be made to improve sedimentation basin performance. For information on tracer studies, see the *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual* (EPA, 2003).

- Is sludge collection and removal adequate? Inadequate sludge collection and removal can cause particles to become re-suspended in water or upset circulation. Systems should disrupt the sludge blanket as little as possible. Sludge draw-off rates can affect the sludge blanket. Sludge draw-off procedures should be checked periodically, making sure sludge levels are low and sludge should be wasted if necessary. Sludge pumping lines should be inspected routinely to ensure that they are not becoming plugged. These lines should also be flushed occasionally to prevent the buildup of solids.

- Do basin inlet and outlet conditions prevent the break-up of formed floc particles? Settling basin inlets are often responsible for creating turbulence that can break up floc. Improperly designed outlets are also often responsible for the breakup of floc. Finger launders (small troughs with V–notch weir openings that collect water uniformly over a large area of a basin) can be used to decrease the chance of floc breakup.

- Is the floc the correct size and density? Poorly formed floc is characterized by small or loosely held particles that do not settle properly and are carried out of the settling basin. Such floc may be the result of inadequate rapid mixing, improper coagulant dosages, or improper flocculation. Systems should look to previous steps in the treatment train to solve this problem.

Systems should verify that the proper detention time is achieved in all sedimentation basins under all flow conditions.

- Is the basin subject to short-circuiting? If the basin is not properly designed, water bypasses the normal flow path through the basin and reaches the outlet in less than the normal detention time. Causes of short-circuiting may include poor influent baffling or improperly placed collection troughs. If the influent enters the basin and hits a solid baffle, strong currents may result. A perforated baffle may distribute inlet water without causing strong currents. Tube or plate settlers may also improve efficiency, especially if flows have increased beyond original design conditions. The installation of tube settlers can sometimes double a basin's original settling capacity.

- Are basins located outside and subject to windy conditions? Wind can create currents in open basins that can cause short-circuiting or disturb the floc. If wind poses a problem, installing barriers may reduce the effect and keep debris out of the unit.

- Are basins subject to algal growth? Although primarily a problem in open, outdoor basins, algae can also grow as a result of window placement around indoor basins. Algae should be removed regularly to avoid buildup.

- Is the sludge blanket in SCUs maintained properly? Operators should be able to measure the sludge depth and percent solids to ensure the sludge blanket is within the manufacturer's recommendations. A timing device to ensure consistent blanket quality characteristics should control sludge removal rates and schedule.

Maintaining an adequate sludge layer will give settling particles something to attach to and reduce the tendency for "floaters."

- Is the recirculation rate for SCUs within the manufacturer's recommendations? Various designs have different recirculation rates and flow patterns. Systems should refer to the manufacturer's operation manual.
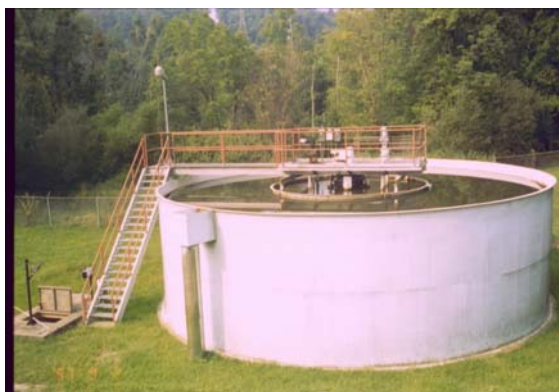
Figure 8-2. Circular Clarifier

See Chapter 5 for more information on filters and filter self-assessments.

8.3.4 Filtration

Filtration is the last step in the particle removal process. Improperly designed, operated, or maintained filters can contribute to poor water quality and sub-optimal performance. A host of factors may be contributing to poor performance, and systems should make a comprehensive evaluation of the filter to identify which factors are responsible. Many of the items listed below are detailed in Chapter 5, Filter Self-Assessment. Appendix H contains an example operating procedure for filter operations.

Design of Filter Beds

If additional media is needed due to loss of media, systems should order media that has the same characteristics (based on effective size and uniformity coefficient) as the existing media.

Systems should verify that the filters are constructed and maintained according to design specifications. Figure 8-3 shows an inspection of filter media. The system should consider the following items when evaluating the design of filter beds:

- Is the correct media being used? Issues such as size and uniformity coefficient should be evaluated. Is the media at the proper depth? Media can be lost during backwash operations or when air trapped in the media is suddenly released. Only a small amount of media may be lost at a time, but it will add up to a substantial reduction in media depth over time. Media depth should be verified and recorded at least annually. Consistent losses may be indicative of other problems such as inadequate freeboard to the wash water

collectors. Media should be added any time the depth changes by more than 2 inches across the filter.

- Are underdrains adequate, or have they been damaged or disturbed?

Figure 8-3. Inspecting Filter Media

Filter Rate and Rate Control

The rate of filtration and rate control are other important aspects of filters that should be evaluated. Without proper control, surges may occur which force suspended particles through the filter media. Items to consider are:

- Do the filters experience sudden flow surges? Systems should avoid sudden changes to filter rates.

- Is the plant operating at the appropriate flow rate? At some plants, the flow is sometimes operated at a level that hydraulically overloads unit processes. Operating at lower flow rates over longer periods of time may prevent overloading and increase plant performance. Underloading filters can also be a problem. If a plant is treating an extremely low flow rate (less than 50 percent of design flow), it may choose to take some filters off-line for a period of time. When filters are taken off-line, they still have standing water in them. A system should not drain the filters since it may take a considerable period of time to regain the proper filter

Systems should verify that filters are not loaded at rates in excess of the design rate under all operational scenarios, such as when other filters are off-line for backwashing.

bed conditions if the filter is drained and allowed to dry. It is usually better to use all filters and allow water to move through the filters instead of taking filters off-line during low plant flow periods. Keeping all filters active typically prevents the growth of microorganisms and anaerobic conditions (Kawamura, 2000). If this mode of operation is not possible, the system may want to consider disinfection of the filter prior to placing it back on-line.

- At what flows are the filters rated? Systems should make sure not to exceed flow rates on remaining in-service filters when taking other filters off-line or out of service for backwash. If possible, systems should take one filter off-line at a time or reduce plant flow to avoid over-loading the filters remaining online. Another issue to consider is not underloading filters. Some filters perform best at the design loading rate. Therefore, the system may need to take filters off-line to achieve the design loading rate during low-flow periods.

Filter Backwashing

Filter backwashing has been identified as a critical step in the filtration process. Many of the operating problems associated with filters may be a result of inadequate or improper backwashing. The system should consider the following items when evaluating filter backwash practices:

See Chapter 5 for more information on filter backwash practices.

- Is the rate of filter backwash appropriate for the filter? Filters can be either underwashed or overwashed. Utilities should determine the appropriate flow that will clean the filter, but will not upset the filter media to the extent that the underdrain is damaged or filter media are lost.

- Are criteria set for initiating backwash? Systems should establish criteria such as time, headloss, turbidity, or particle counts for initiating backwash procedures. If more than one criterion is used, the criteria should be prioritized to identify which one is most critical for establishing when to backwash the filter.

Criteria that may initiate a backwash could be:
- time;
- headloss; or,
- turbidity/particle counts.

- How are filters brought back on-line? Media should be allowed to settle after backwashing and before bringing filters back on-line. Filters should be brought back on-line slowly. They should not be brought back on-line

without backwashing first.

- When a filter is backwashed, is more water diverted to the remaining filters, causing them to be overloaded during backwash? During the backwash, flow going to the remaining filters may need to be cut back to ensure the filters are not overloaded or "bumped" with a hydraulic surge causing particle pass-through.

- Is flow divided equally among the filters that are on-line?

- Is the filter started slowly (i.e., is the loading rate gradually increased until the design hydraulic loading rate is achieved)? This will purge air trapped in the media. The use of a backwash pump to purge air to "bump" the filter is generally not considered a safe or acceptable practice. It can disrupt the filter media or underdrain system, resulting in filter breakthrough.

Air Binding

Air binding happens when large amounts of air bubbles accumulate in the filter bed. This may result in large headlosses through the filter bed. If a high water level is maintained in the filter, air binding may be minimized due to the increased head applied to the bed. This practice may not be possible with some package plants because package plants are limited in the depth of water over the filter. Air binding may be more common with cold water or during the spring, when there is a high concentration of dissolved air in the water. The degree of air binding may be reduced or even eliminated if filter backwashing is frequently initiated whenever the headloss reaches 4 to 5 feet (Kawamura, 2000).

Control of Initial Turbidity Breakthrough

See Chapter 5 for more information on filter spikes.

Systems may sometimes have a high initial turbidity breakthrough after placing a filter back on-line after backwashing. This breakthrough can be controlled by (Logsdon, et al., 2000):

- Filter to waste;

- Delayed start of the filter;

- Slowly starting the filter;

- Adding polymer or coagulant to backwash water; and/or,

- Adding coagulant chemical or cationic polymer to settled water as it fills the filter box after backwash is terminated.

- Filter-to-waste

Filter-to-waste consists of wasting water to a site other than the clearwell until the filter effluent meets an acceptable turbidity (0.3 NTU for direct and conventional treatment plants) or particle count value. Some utilities may filter-to-waste for a preset time, but filter-to-waste may be more effective if terminated based on a specific turbidity or particle count value. Some filtration plants may not have adequate piping to carry the wasted filtrate when the filter is operated at its full filtration rate. In this circumstance, filter-to-waste should be conducted with the filter operating at a reduced rate, and after filter-to-waste has ended, the filtration rate should be increased to the appropriate level (Logsdon, et al, 2000). Systems should carefully manage the filter rate change, because sudden increases in the hydraulic loading rate could also result in unwanted turbidity spikes. If a plant does have filter-to-waste capabilities, it should make sure that the waste line does not create a cross connection for the plant. One method to consider is to provide an air gap between the filter waste line and the receiving device (whether it is a recycle line, sanitary sewer pipe, or trough).

- Delayed start of the filter

Delayed start of the filter has also been shown to reduce initial turbidity spikes. One study of three plants showed up to 50 percent reduction in peak particle counts between delayed start filters and filters that were placed on-line immediately after backwash (Hess, et al., 2000). Systems should be aware that resting a filter before starting a new run is not a cure-all; some plants have reported that the delayed start did not consistently control initial turbidity.

- Slow-starting the filter

Slow-starting a filter consists of starting the filter at a low filtration rate and gradually increasing the rate over a period of time, such as 15 minutes. To slow-start a filter, the filter should be equipped with rate control valves that can be gradually increased. Again, this approach is not a cure-all. It has been found to be effective at some plants while failing to eliminate the initial turbidity spike at other plants (Hess, et al., 2000).

- Systems should consider adding polymer and/or coagulant

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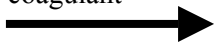
Systems could also consider adding a coagulant during the backwash process. Some studies have shown that coagulants added during backwash can accelerate the filter ripening process and reduce initial turbidity spikes (Hess, et al., 2000). The coagulant is typically added during the last couple of minutes of backwash.

The Milwaukee Water Works compared filter performance for three different scenarios (Carmichael, Lewis, and Aquino, 1998):

- Backwash with no polymer addition;

- Backwash with cationic polymer (Cat-Floc T) added to the backwash water; and,

- Cationic polymer added to the influent settled water for the last hour of a filter run and again during the first hour of the following run.

Adding 0.4 mg/L of polymer to the influent settled water before and after backwash controlled the initial spike better than adding polymer to the backwash water. Filter performance was measured based on particle counting. Full-scale practice has been modified to include addition of a slug dose (0.4 mg/L) of undiluted cationic polymer in the filter box in front of the influent valve as the settled water flows into the filter box after the influent valve is opened. Then, during the first hour of the filter run, polymer is fed at a dose of 0.4 mg/L. Polymer is no longer fed during the last hour of a filter run before backwash, because it did not improve filter performance (Hess, et al., 2000).

CAUTION

Systems should be careful not to overfeed chemicals since this practice can result in mudballs and plugging of the filter.

If a system chooses to add a coagulant or polymer, keep in mind that more is not always better. Overdosing either an inorganic coagulant or a polymer could have a negative effect on the filter. Applying chemical overdose for too long at the beginning of a run may cause filtered water turbidity to rise at the end of the dosing. In addition, if excessive alum is added to the influent settled water, mudballs might develop in the filter. Excess polymer dosages can also result in short filter runs and mudball formation (Hess, et al., 2000). Systems should start at very low coagulant or polymer dosages and gradually increase the dose until positive effects are seen in the filtered effluent quality.

Systems should also perform filter runs with and without the coagulant or polymer for comparison purposes.

Some utilities have found that using a combination of the above procedures provides the best control of initial turbidity spikes.

Turbidity Breakthrough in Late Stages of the Filter Cycle

Filters may sometimes experience high turbidity or sudden spikes prior to the end of the filter cycle, as shown in Figure 5-5. This type of breakthrough can be controlled by strengthening the floc and increasing the adsorption capability of the filter bed. Two options a system should consider are to feed cationic polymer as a coagulant, with or without alum, or to feed minute amounts of nonionic polymer to the filter influent as a filtration aid. Systems should be careful to limit the dosage of the nonionic polymer (0.015 to 0.025 mg/L) to prevent short filter runs or mudballs (Kawamura, 2000). Beware that polymers can sometimes counteract each other, and the addition of one polymer may require a system to increase the feed amount of another polymer. Again, keep in mind that more is not always better.

CAUTION

When adding polymers as a filtration aide, systems should be careful not to add a polymer that will counteract another chemical. Counteraction will not improve filtration and may cause additional problems.

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Appendix A
Glossary

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A.1 GLOSSARY

accuracy. How closely an instrument measures the true or actual value of the process variable being measured or sensed. Also see precision.

acidic. The condition of water or soil that contains a sufficient amount of acid substances to lower the pH below 7.0.

activated carbon. Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble organic materials from water.

air binding. A situation where air collects within the filter media.

algae. Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. They are food for fish and small aquatic animals.

alkaline. The condition of water or soil that contains a sufficient amount of alkali substances to raise the pH above 7.0.

alkalinity. The capacity of water to neutralize strong acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

available expansion. The vertical distance from the filter surface to the overflow level of a trough in a filter. This distance is also called freeboard.

backwash. The process of reversing the flow of water back through the filter media to remove the entrapped solids.

bacteria. Singular: bacterium. Microscopic living organisms usually consisting of a single cell. Some bacteria in soil, water or air may also cause human, animal and plant health problems.

baffle. A flat board or plate, deflector, guide or similar device constructed or placed in flowing water or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids (water, chemical solutions, slurry).

breakthrough. A condition whereby filter effluent water quality deteriorates (as measured by an increase in turbidity, particle count, or other contaminant). This may occur due to excessive filter run time or hydraulic surge.

calcium carbonate (CaCO₃) equivalent. An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water that is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

calibration. A procedure that checks or adjusts an instrument's accuracy by comparison with a standard or reference sample that has a known value.

capital costs. Costs of construction and equipment. Capital costs are usually fixed, one-time expenses, although they may be paid-off over longer periods of time.

carcinogen. Any substance which tends to cause cancer in an organism.

clarifier. A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom by gravity. Clarifiers are also called settling basins and sedimentation basins.

clearwell. A reservoir for the storage of filtered water with sufficient capacity to prevent the need to vary the filtration rate in response to short-term changes in customer demand. Also used to provide chlorine contact time for disinfection.

coagulant aid. A chemical added during coagulation to improve the process by stimulating floc formation or by strengthening the floc so it holds together better.

coagulant. A chemical added to water that has suspended and colloidal solids to destabilize particles, allowing subsequent floc formation and removal by sedimentation, filtration, or both.

coagulation. As defined in 40 CFR 141.2, a process using coagulant chemicals and mixing by which colloidal and suspended materials are destabilized and agglomerated into flocs.

cohesion. Molecular attraction that holds two particles together.

colloid. A small, discrete solid particle in water that is suspended (not dissolved) and will not settle by gravity because of molecular bombardment.

combined filter effluent. Generated when the effluent water from individual filters in operation is combined into one stream.

combined sewer. A sewer that transports surface runoff and human domestic wastes (sewage), and sometimes industrial wastes.

community water system (CWS). As defined in 40 CFR 141.2, a public water system which serves at least 15 service connections used by year round residents or regularly serves at least 25 year-round residents.

continuous sample. A constant flow of water from a particular place in a plant to the location where samples are collected for testing.

conventional filtration treatment. As defined in 40 CFR 141.2, a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal.

cross connection. Any actual or potential connection between a drinking (potable) water system and an unapproved water supply or other source of contamination. For example, if a pump moving nonpotable water is hooked into the water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

Cryptosporidium. A disease-causing protozoan widely found in surface water sources. *Cryptosporidium* is spread as a dormant oocyst from human and animal feces to surface water. In its dormant stage, *Cryptosporidium* is housed in a very small, hard-shelled oocyst form that is resistant to chorine and chloramine disinfectants. When water containing these oocysts is ingested, the protozoan causes a severe gastrointestinal disease called cryptosporidiosis.

CT or CT$_{calc}$. As defined in 40 CFR 141.2, the product of "residual disinfectant concentration" (C) in mg/L determined before or at the first customer, and the corresponding "disinfectant contact time" (T) in minutes, i.e., "C" x "T". If a public water system applies disinfectants at more than one point prior to the first customer, it must determine the CT of each disinfectant sequence before or at the first customer to determine the total percent inactivation or "total inactivation ratio". In determining the total inactivation ratio, the public water system must determine the residual disinfectant concentration of each disinfection sequence and corresponding contact time before any subsequent disinfection application point(s). "CT$_{99.9}$" is the CT value required for 99.9 percent (3-log) inactivation of *Giardia lamblia* cysts. CT$_{99.9}$ for a variety of disinfectants and conditions appear in 40 CFR 141.74(b)(3) Tables 1.l- 1.6, 2.1, and 3.1. CT$_{calc}$/CT$_{99.9}$ is the inactivation ratio. The sum of the inactivation ratios, or total inactivation ratio shown as Σ [(CT$_{calc}$) / (CT$_{99.9}$)] is calculated by adding together the inactivation ratio for each disinfection sequence. A total inactivation ratio equal to or greater than 1.0 is assumed to provide a 3-log inactivation of *Giardia lamblia* cysts.

d$_{60\%}$. The diameter of the particles in a granular sample (filter media) for which 60 percent of the total grains are smaller and 40 percent are larger on a weight basis. The d$_{60\%}$ is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve.

degasification. A process that removes dissolved gases from the water. The gases may be removed by either mechanical or chemical treatment methods or a combination of both.

degradation. Chemical or biological breakdown of a complex compound into simpler compounds.

diatomaceous earth filtration. As defined in 40 CFR 141.2, a process resulting in substantial particulate removal, that uses a process in which: (1) a "precoat" cake of diatomaceous earth filter media is deposited on a support membrane (septum), and (2) while the water is filtered by passing through the cake on the septum, additional filter media, known as "body feed," is continuously added to the feed water to maintain the permeability of the filter cake.

direct filtration. As defined in 40 CFR 141.2, a series of processes including coagulation and filtration but excluding sedimentation resulting in substantial particulate removal.

effective range. That portion of the design range (usually upper 90 percent) in which an instrument has acceptable accuracy.

effective size (E.S.). The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

effluent. Water or some other liquid that is raw, partially treated or completely treated that is flowing from a reservoir, basin, treatment process or treatment plant.

enteric. Of intestinal origin, especially applied to wastes or bacteria.

entrain. To trap bubbles in water either mechanically through turbulence or chemically through a reaction.

EPA. United States Environmental Protection Agency.

epidemic. An occurrence of cases of disease in a community or geographic area clearly in excess of the number of cases normally found (or expected) in that population for a particular season or other specific time period. Disease may spread from person to person, and/or by the exposure of many persons to a single source, such as a water supply.

filtration. As defined in 40 CFR 141.2, a process for removing particulate matter from water by passage through porous media.

finished water. Water that has passed through a water treatment plant such that all the treatment processes are completed or "finished." This water is ready to be delivered to consumers. Also called product water.

floc. Collections of smaller particles that have come together (agglomerated) into larger, more settleable particles as a result of the coagulation-flocculation process.

flocculation. As defined in 40 CFR 141.2, a process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles through gentle stirring by hydraulic or mechanical means.

fluidization. The upward flow of a fluid through a granular bed at sufficient velocity to suspend the grains in the fluid and depends on filter media properties, backwash temperature, and backwash water flow rates.

garnet. A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

gastroenteritis. An inflammation of the stomach and intestine resulting in diarrhea, with vomiting and cramps when irritation is excessive. When caused by an infectious agent, it is often associated with fever.

Giardia lamblia. Flagellated protozoan which is shed during its cyst-stage with the feces of man and animals. When water containing these cysts is ingested, the protozoan causes a severe gastrointestinal disease called giardiasis.

giardiasis. Intestinal disease caused by an infestation of *Giardia* flagellates.

grab sample. A single sample collected at a particular time and place that represents the composition of the water only at that time and place.

ground water under the direct influence (GWUDI) of surface water. As defined in 40 CFR 141.2, any water beneath the surface of the ground with significant occurrence of insects or other macroorganisms, algae, or large-diameter pathogens such as *Giardia lamblia* or *Cryptosporidium*, or significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the State. The State determination of direct influence must be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation.

hardness, water. A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water.

head. The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

head loss. A reduction of water pressure in a hydraulic or plumbing system.

humus. Organic portion of the soil remaining after prolonged microbial decomposition.

influent water. Raw water plus recycle streams.

in-line filtration. The addition of chemical coagulants directly to the filter inlet pipe. The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated. This pretreatment method is commonly used in pressure filter installations.

jar test. A laboratory procedure that simulates a water treatment plant's coagulation, rapid mix, flocculation, and sedimentation processes. Differing chemical doses, energy of rapid mix, energy of slow mix, and settling time can be examined. The purpose of this procedure is to estimate the minimum or optimal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of a single chemical are added to each jar while holding all other chemicals at a consistent dose, and observing the formation of floc, settling of solids, and resulting water quality.

microbial growth. The activity and growth of microorganisms such as bacteria, algae, diatoms, plankton and fungi.

micrograms per liter (μg/L). One microgram of a substance dissolved in each liter of water. This unit is equal to parts per billion (ppb) since one liter of water is equal in weight to one billion micrograms.

micron. A unit of length equal to one micrometer (μm), one millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

microorganisms. Living organisms that can be seen individually only with the aid of a microscope.

milligrams per liter (mg/L). A measure of concentration of a dissolved substance. A concentration of one mg/L means that one milligram of a substance is dissolved in each liter of water. For practical purposes, this unit is equal to parts per million (ppm) since one liter of water is equal in weight to one million milligrams.

mudball. Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. This material forms in filters and gradually increases in size when not removed by the backwashing process.

nephelometric. A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

nephelometric turbidity unit (NTU). The unit of measure for turbidity.

non-community water system (NCWS). As defined in 40 CFR 141.2, a public water system that is not a community water system. A non-community water system is either a "transient non-community water system (TWS)" or a "non-transient non-community water system (NTNCWS)."

non-transient non-community water system (NTNCWS). As defined in 40 CFR 141.2, a public water system that is not a community water system and that regularly serves at least 25 of the same persons over six months per year.

operation and maintenance costs. The ongoing, repetitive costs of operating and maintaining a water system; for example, employee wages and costs for treatment chemicals and periodic equipment repairs.

organics. Carbon-containing compounds that are derived from living organisms.

overflow rate. A measurement used in the design of settling tanks and clarifiers in treatment plants which relates the flow to the surface area. It is used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Overflow rate may be expressed as either gallons per day per square foot (gpd/sq ft) or gallons per minute per square foot (gpm/ sq ft). Overflow Rate (GDP/sq ft) = Flow (GPD)/Surface Area (sq ft).

particle count. The results of a microscopic-scale examination of treated water with a special "particle counter" that classifies suspended particles by number and size.

particulate. A very small solid suspended in water which can vary widely in shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.

pathogens, or pathogenic organisms. Microorganisms that can cause disease (such as typhoid, cholera, dysentery) in other organisms or in humans, animals and plants. They may be bacteria, viruses, or protozoans and are found in sewage, in runoff from animal farms or rural areas populated with domestic and/or wild animals, and in water used for swimming. There are many types of organisms which do not cause disease. These organisms are called non-pathogens.

pH. pH is an expression of the intensity of the basic or acid condition of a solution. Mathematically, pH is the negative logarithm (base 10) of the hydrogen ion concentration, [H+]. [pH = log (1/H+)]. The pH may range from 0 to 14, where 0 is most acidic, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

plug flow. The water travels through a basin, pipe, or unit process in such a fashion that the entire mass or volume is discharged at exactly the theoretical detention time of the unit.

polymer. A synthetic organic compound with high molecular weight and composed of repeating chemical units (monomers). Polymers may be polyelectrolytes (such as water-soluble flocculants), water-insoluble ion exchange resins, or insoluble uncharged materials (such as those used for plastic or plastic-lined pipe).

pore. A very small open space.

precision. The ability of an instrument to measure a process variable and to repeatedly obtain the same result.

primary standard.   A solution used to calibrate an instrument.

public water system. As defined in 40 CFR 141.2, a system for the provision to the public of water for human consumption through pipes or, after August 5, 1998, other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily, at least 60 days out of the year. Such term includes: any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. Such term does not include any "special irrigation district." A public water system is either a "community water system" or a "non-community water system".

reservoir. Any natural or artificial holding area used to store, regulate, or control water.

reverse osmosis. The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). The liquid produced is a demineralized water.

Safe Drinking Water Act (SDWA). Commonly referred to as SDWA. A law passed by the U.S. Congress in 1974.

sand. Soil particles between 0.05 and 2.0 mm in diameter.

sand filter. The oldest and most basic filtration process, which generally uses two grades of sand (coarse and fine) for turbidity and particle removal. A sand filter can serve as a first-stage roughing filter or prefilter in more complex processing systems.

secondary standard (for turbidity). Commercially prepared, stabilized, sealed liquid or gel turbidity standards that are used to verify the continued accuracy of a calibrated instrument. The actual value of the secondary standard must be determined by comparing it against properly prepared and diluted primary standard such as formazin or styrene divinylbenzene polymers. Secondary standards should not be used to calibrate an instrument.

sedimentation. As defined in 40 CFR 141.2, a process for removal of solids before filtration by gravity or separation.

slow sand filtration. As defined in 40 CFR 141.2, a process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 meters per hour) resulting in substantial particulate removal by physical and biological mechanisms.

standard. A physical or chemical quantity whose value is known exactly, and is used to calibrate or standardize instruments. See also primary standards and secondary standards.

standardize. To compare with a standard. 1) In wet chemistry, to find out the exact strength of a solution by comparing it with a standard of known strength. 2) To set up an instrument or device to read a standard. This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

State. As defined in 40 CFR 141.2, the agency of the State or Tribal government which has jurisdiction over public water systems. During any period when a State or Tribal government does not have primary enforcement responsibility pursuant to Section 1413 of the Safe Drinking Water Act, the term "State" means the Regional Administrator, U.S. Environmental Protection Agency.

surface water. As defined in 40 CFR 141.2, all water which is open to the atmosphere and subject to surface runoff.

surfactant. Abbreviation for surface-active agent. A chemical that, when added to water, lowers surface tension and increases the "wetting" capabilities of the water. Reduced surface tension allows water to spread and to penetrate fabrics or other substances, enabling them to be washed or cleaned. Soaps and wetting agents are typical surfactants.

suspended solids. Solid organic and inorganic particles that are held in suspension by the action of flowing water and are not dissolved.

transient non-community water system. As defined in 40 CFR 141.2, a non-community water system that does not regularly serve at least 25 of the same persons over six months per year.

tube settlers. Bundles of small-bore (2 to 3 inches or 50 to 75 mm) tubes installed on an incline as an aid to sedimentation. As water rises in the tubes, settling solids fall to the tube surface. As the sludge (from the settled solids) in the tube gains weight, it moves down the tubes and settles to the bottom of the basin for removal by conventional sludge collection means. Tube settlers are sometimes installed in sedimentation basins and clarifiers to improve settling of particles.

turbid. Having a cloudy or muddy appearance.

turbidimeter. A device that measures the amount of light scattered by suspended particles in a liquid under specified conditions.

turbidity. The cloudy appearance of water caused by the presence of suspended and colloidal matter.

uniformity coefficient. A measure of how well a sediment is graded.

verification. A procedure to verify the calibration of an instrument such as a turbidimeter.

virus. As defined in 40 CFR 141.2, a virus of fecal origin which is infectious to humans by waterborne transmission.

water supplier. A person who owns or operates a public water system.

water supply system. The collection, treatment, storage, and distribution of potable water from source to consumer.

zeta potential. The electric potential arising due to the difference in the electrical charge between the dense layer of ions surrounding a particle and the net charge of the bulk of the suspended fluid surrounding the particle. The zeta potential, also known as the electrokinetic potential, is usually measured in millivolts and provides a means of assessing particle destabilization or charge neutralization in coagulation and flocculation procedures.

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Appendix B
Blank Forms and Checklists

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This appendix contains blank versions of the forms, checklists, and worksheets found in Chapters 1 through 8 of this Guidance Manual.

- A completed example of the Turbidimeter Maintenance Form can be found in Chapter 3 of this Guidance Manual.

- A completed example of the Calibration Checklist Form can be found in Chapter 3 of this Guidance Manual.

- A completed example of the Filter Self-Assessment Checklist can be found in Chapter 5 of this Guidance Manual.

- A completed example of the Individual Filter Self-Assessment Form can be found in Chapter 5 of this Guidance Manual.

- Completed Worksheets 1 and 2 can be found in Chapter 4.

Turbidimeter Maintenance Form					
Instrument:					
Date	Verification	Acceptable/ Unacceptable	Maintenance Performed	Initials	Comments

CALIBRATION CHECKLIST

Instrument _____

Date	Initials	Recorded Value (NTU)	Value of Standard (NTU)	Comments

Filter Self-Assessment Checklist

System Name   _____
Filter #   _____
Date Self-Assessment was Triggered _____
Date of Self-Assessment_____

_____   Assessment of Filter Performance

_____   Development of a Filter Profile

_____   Identification and Prioritization of Factors Limiting Filter Performance

_____   Assessment of the Applicability of Corrections

_____   Preparation of a Filter Self-Assessment Report

Individual Filter Self-Assessment Form[†]

Topic	Description	Information	
		Actual	**Design**
General Filter Information	Type (mono, dual, mixed, pressure, gravity)		
	Number of filters		
	Filter/rate control (constant, declining)		
	Type of flow control (influent weir, valves)		
	Surface wash type (rotary, fixed, none)/air scour		
	Configuration (rectangular, circular, square, horizontal, vertical)		
	Dimensions (length, width, diameter, height of side walls)		
	Max depth of water above media		
	Surface area per filter (ft^2)		
Hydraulic Loading Conditions	Average operating flow (mgd or gpm)		
	Peak instantaneous operating flow (mgd or gpm)		
	Average hydraulic surface loading rate (gpm/ft^2)		
	Peak hydraulic surface loading rate (gpm/ft^2)		
	Changes in hydraulic loading rate (gpm/ft^2)		
Media Conditions	Depth, type, uniformity coefficient[*], and effective size[*]		
	Media 1[*]		
	Media 2[*] (if applicable)		
	Media 3[*] (if applicable)		
	Presence of mudballs, debris, excess chemical, cracking, worn media, media coating		

[†]This worksheet is designed to elicit additional information and is not required under 40 CFR Section 141.563(b).
*You may want to have a sieve analysis done on the media. Note that a sieve analysis may not be completed within the 14-day time frame required for a filter self-assessment.

Individual Filter Self-Assessment Form (continued)

Topic	Description	Information	
		Actual	**Design**
Support Media/Under-drain Conditions	Is the support media evenly placed (deviation <2 inches measured vertically) in the filter bed?		
	Type of underdrains		
	Evidence of media in the clearwell or plenum		
	Evidence of boils during backwash		
Backwash Practices	Backwash initiation (headloss, turbidity/particle counts, time)		
	Sequence (surface wash, air scour, flow ramping, filter-to-waste)		
	Duration (minutes) of each step		
	Introduction of wash water (via pump, head tank, distribution system pressure)		
	Backwash rate (gpm/ft^2) at each step		
	Bed expansion (percent)		
	Dose of coagulants or polymers added to wash water		
	Backwash termination (time, backwash turbidity, visual inspection, or other)		
	Backwash SOP (exists and current)		
Placing a Filter Back into Service	Delayed start, slow start, polymer addition, or filter to waste		
Rate-of-Flow Controllers and Filter Valves	Leaking valves		
	Malfunction rate of flow control valves		
	Equal flow distribution to each filter		
Other Considerations	Chemical feed problems		
	Rapid changes in raw water quality		
	Turbidimeters (calibrated)		
	Other		

The following worksheets can be used to collect data to be submitted to the State. Systems should check with the State before using these worksheets to make sure they are acceptable.

Worksheet 1 is a monthly report for combined filter effluent in conventional and direct filtration plants. The worksheet tracks the number of samples per day, maximum daily combined filter effluent, number of turbidity measurements, number of turbidity measurements <= 0.3 NTU, and number of turbidity measurements > 1 NTU. The worksheet will then total the number of turbidity measurements, the number of turbidity measurements <= 0.3 NTU, and the number of turbidity measurements > 1 NTU. The worksheet then finds the percentage of turbidity measurements that meet the specified limits.
Worksheet 2 is a monthly summary report of data for individual filter effluent in conventional and direct filtration plants. This worksheet tracks the filter #, whether or not 15-minute turbidity values were recorded, and the values of turbidity measurements where two or more consecutive 15-minute turbidity readings were greater than 1.0 NTU. It also tracks the values of turbidity measurements > 2.0 NTU for two or more consecutive 15-minute readings.

Worksheet 3 is a monthly report for combined filter effluent in slow sand, diatomaceous earth, or other alternative filtration technology plants. This worksheet is the same as worksheet 1, but formatted for slow sand, diatomaceous earth, or other alternative filtration technologies.

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WORKSHEET 1
CONVENTIONAL AND DIRECT FILTRATION PLANTS
MONTHLY REPORT FOR COMBINED FILTER EFFLUENT
Due by the 10th of the Following Month

Check with your State or Primacy Agency to make sure this form is acceptable.

Month: _____   System/Treatment Plant: _____
Year: _____
PWSID: _____

A	B Number of Samples Required Per Day	C[1] Maximum Combined Filter Effluent	D[2] No. of Turbidity	E No. of Turbidity Measurements	F No. of Turbidity Measurements
Day	Samples/Day	NTU	Measurements	<= 0.3 NTU	>1 NTU
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
		Totals:			

Number of monthly readings (Total of Column D) = _____
Number of monthly readings <= 0.3 NTU (Total of Column E) = _____
The percentage of turbidity measurements meeting the specified limits.
= (Total of Column E / Total of Column D) x 100 = _____%

Record the date and turbidity value for any measurements exceeding 1 NTU (Contact State within 24 hours):
If none, enter "None."

Prepared by: _____

Date: _____

Date	Turbidity Readings > 1 NTU

Was individual filter effluent monitored continuously (at least every 15 minutes) during the month?
Yes _____   No _____

Notes:

1. To complete Column B, enter the number of required samples for the day based on hours of plant operation or as allowed by the State. Systems that do not operate 24 hours per day will need to check with their State on required sampling frequency.

2. To complete Column C, report the highest combined filter effluent turbidity value of those recorded at the 4-hour intervals.

3. To complete Column D, enter the number of turbidity measurements taken each day, not the actual turbidity values obtained.

Records of the combined filter effluent turbidity monitoring results must be retained by the public water system supplier. The system must report to the State or Primacy Agency by the 10th of the following month:

- The total number of filtered water turbidity measurements taken during the month.

- The number and percentage of filtered water turbidity measurements taken during the month which are less than or equal to 0.3 NTU.

- The date and value of any turbidity measurements taken during the month which exceed 1 NTU.

WORKSHEET 2
CONVENTIONAL AND DIRECT FILTRATION PLANTS
MONTHLY SUMMARY REPORT OF DATA FOR INDIVIDUAL FILTER EFFLUENT
Check with your State or Primacy Agency to make sure this form is acceptable.

Year: _____   System Name: _____
PWSID: _____   Filter Number: _____

A Date	B Were 15-min Turbidity Values Recorded?	C Values of Turbidity Measurements > 1.0 NTU for two or more consecutive 15-min readings	D Value of Turbidity Measurements > 2.0 NTU for two or more consecutive 15-min readings

Did the filter exceed 1.0 NTU in two or more consecutive 15-minute readings this month? _____ No
_____ Yes - Report to the State by the 10th of the following month the filter number(s),
corresponding date(s), and turbidity value(s) which exceeded 1.0 NTU and
the cause, if known.
Did this occur in the two previous months? _____ No
_____ Yes - Must conduct a filter self-assessment within 14 days of the
exceedance unless a CPE was required.
Did the filter exceed 2.0 NTU in two or more consecutive 15-minute readings this month? _____ No
_____ Yes - Did this occur in the previous month? _____ No
_____ Yes - Must arrange for a CPE unless a CPE has been completed by
the State or third party approved by the State within the 12
prior months or the system and State are jointly participating
in an ongoing Comprehensive Technical Assistance project
at the system.

Notes:

This worksheet can be used for multiple months as a recordkeeping tool for the system. The system may want to modify this sheet to allow daily recording of individual filter effluent turbidity monitoring and the system could use a new worksheet for each month.

A. Enter the date in this column.

B. System must report by 10th of the following month that the individual filter effluent turbidity was continuously monitored.

C. Enter number of incidents where two or more consecutive 15-minute turbidity readings for an individual filter exceeded 1.0 NTU. The system must report to the State the filter number, corresponding date(s), and turbidity value(s) which exceeded 1.0 NTU for two consecutive 15-minute measurements each month by the 10th of the following month.

D. Enter the number of incidents where two or more consecutive 15-minute turbidity readings for an individual filter exceeded 2.0 NTU.

WORKSHEET 3
SLOW SAND, DIATOMACEOUS EARTH, OR ALTERNATIVE FILTRATION TECHNOLOGY
MONTHLY REPORT FOR COMBINED FILTER EFFLUENT
Due by the 10th of the Following Month

Check with your State or Primacy Agency to make sure this form is acceptable.

Month: _____   System/Treatment Plant: _____

Year: _____   Treatment Type[1]: _____

PWSID: _____

A	B	C[2]	D[3]	E	F
Day	Number of Samples Required Per Day Samples/Day	Maximum Combined Filter Effluent NTU	No. of Turbidity Measurements	No. of Turbidity Measurements <=1 NTU	No. of Turbidity Measurements >5 NTU
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
Totals:					

Number of monthly readings (Total of Column D) = _____
Number of monthly readings <= 1 NTU (Total of Column E) = _____
The percentage of turbidity measurements meeting the specified limits.
= (Total of Column E / Total of Column D) x 100 = _____%

Record the date and turbidity value for any measurements exceeding 5 NTU (Contact State within 24 hours):
If none, enter "None."

Prepared by: _____

Date: _____

Date	Turbidity Readings > 5 NTU

Notes:

1. Treatment type refers to Slow Sand, Diatomaceous Earth, or alternative filtration technology. Treatment type should be your current operational practice.

2. To complete Column B, enter the number of required samples for the day based on hours of plant operation or as allowed by the State. Systems that do not operate 24 hours per day will need to check with their State on required sampling frequency.

3. To complete Column C, report the highest combined filter effluent turbidity value of those recorded at the 4-hour intervals.

4. To complete Column D, enter the number of turbidity measurements taken each day, not the actual turbidity values obtained.

Appendix C
Equations and Sample Calculations

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ABBREVIATIONS

ac	=	acre	**ha**	=	hectare	**mi**	=	mile
cfs	=	cubic feet per second	**hr**	=	hour	**min**	=	minute
cm	=	centimeter	**in**	=	inches	**mL**	=	milliliter
d	=	diameter	**in³**	=	cubic inches	**ppm**	=	parts per million (mg/L)
ft	=	feet	**kg**	=	kilogram	**r**	=	inner radius
ft³	=	cubic feet	**L**	=	liter	**sec**	=	second
gal	=	gallons	**lbs**	=	pounds	**Sp Gr**	=	specific gravity
gpd	=	gallons per day	**mg**	=	milligrams	**sq ft**	=	square feet
gpm	=	gallons per minute	**MG**	=	million gallons	**sq in**	=	square inches
gpg	=	grains per gallon	**MGD**	=	million gallons per day	**sq m**	=	square meters
g	=	grams	**m³**	=	cubic meters	**yd**	=	yard

CONVERSION FACTORS

AREA:
1 sq ft = 144 sq in or 144 sq in/sq ft
1 ac = 43,560 sq ft or 43,560 sq ft/ac

DOSAGE:
1 grain/gal = 17.1 mg/L or 17.1 mg/L/gpg
1 mg = 64.7 grains or 64.7 grains/mg

LENGTH:
1 ft = 12 in or 12 in/ft
1 yd = 3 ft or 3 ft/yd
1 mi = 5,280 ft or 5,280 ft/mi

UNITS:
1 million = 1,000,000 = 1×10^6

VOLUME:
1 ft³ = 7.48 gal or 7.48 gal/ft³
1 liter = 1,000 mL or 1,000 mL/L
1 gal = 3.785 L or 3.785 L/gal
1 gal = 231 in³ or 231 in³/gal

DENSITY:
1 gal = 8.34 lbs or 8.34 lbs/gal
1 ft³ = 62.4 lbs or 62.4 lbs/ ft³

FLOW:
1 MGD = 694 gpm or 694 gpm/MGD
1 MGD = 1.55 cfs or 1.55 cfs/MGD

TIME:
1 min = 60 sec or 60 sec/min
1 hr   = 60 min or 60 min/hr
1 day = 24 hr or 24 hr/day

WEIGHT:
1 g = 1,000 mg or 1,000 mg/g
1 kg = 1,000 g or 1,000 g/kg
1 lb = 454 g or 454 g/lb
1 kg = 2.2 lbs or 2.2 lbs/kg

CONVERSION FACTORS (Metric System)

AREA:
1 ha = 2.47 ac or 2.47 ac/ha
1 ha = 10,000 sq m or 1,000 sq m/ha

DENSITY:
1 liter = 1 kg or 1 kg/L

VOLUME:
1 m^3 = 1,000 L or 1,000 L/ m^3
1 gal = 3.785 L or 3.785 L/gal

LENGTH:
1 m = 100 cm or 100 cm/m
1 m = 3.28 ft or 3.28 ft/m

FLOW:
1 MGD = 3,785 m^3 or 3,785 m^3/MGD

WEIGTH:
1 gm = 1,000 mg or 1,000 mg/gm
1 kg = 1,000 gm or 1,000 gm/kg

FORMULAS

I. *FLOWS:*

1) Flow, gpm $= \dfrac{(\text{Flow, MGD})(1{,}000{,}000 \text{ gal / MG})}{(60 \text{ min / hr})(24 \text{ hr / day})}$

or

2) Flow, MGD $= \dfrac{(\text{Flow, GPM})(60 \text{ min / hr})(24 \text{ hr / day})}{1{,}000{,}000 \text{ gal / MG}}$

II. *CHEMICAL FEEDS:*

A. Dry Chemicals (Weight-based)

1) Feed Rate, lb/day $= \dfrac{(\text{Feed Rate, g / min})(1440 \text{ min / day})}{454 \text{ g / lb}}$

2) Dosage, ppm $= \dfrac{\text{Feed Rate, lb / day}}{(\text{Flow, MGD})(8.34 \text{ lb / gal})}$

B. Liquid Chemicals (Volume-based)

1) Feed Rate, gal/day $= \dfrac{(\text{Feed Rate, mL / min})(1440 \text{ min / day})}{3{,}785 \text{ mL / gal}}$

2) Dosage, ppm $= \dfrac{\text{Feed Rate, gal / day}}{\text{Flow, MGD}}$

C. Liquid Chemicals (Liquid Weight-based)

1) Feed Rate, lb/day $= \dfrac{(\text{Feed Rate, mL / min})(1440 \text{ min / day})(\text{Sp Gr})(8.34 \text{ lb / gal})}{3{,}785 \text{ mL / gal}}$

2) Dosage, ppm $= \dfrac{\text{Feed Rate, lb / day}}{(\text{Flow, MGD})(8.34 \text{ lb / gal})}$

D. Liquid Chemicals (Dry Weight-based)

1) Feed Rate, dry lb/day

$$= \dfrac{(\text{Feed Rate, mL / min})(1440 \text{ min / day})(\text{Sp Gr})(\% \text{ concentration})(8.34 \text{ lb / gal})}{(3{,}785 \text{ mL / gal})(100 \%)}$$

2) Dosage, ppm $\qquad = \dfrac{\text{Feed Rate, dry lb / day}}{(\text{Flow, MGD})(8.34\,\text{lb / gal})}$

III. CHEMICAL DOSES:

A. Calibration of a Dry Chemical Feeder:

Chemical Feed Rate, lb/day $\quad = \dfrac{\text{Chemical Applied, lbs}}{\text{Length of Application, day}}$

B. Calibration of a Solution Chemical Feeder:

1) Chemical Feed, lbs/day

$$= \dfrac{(\text{Chem Conc, mg / L})(\text{Vol Pumped, mL})(60\,\text{min / hr})(24\,\text{hr / day})}{(\text{Time Pumped, min})(1000\,\text{mL / L})(1000\,\text{mg / gm})(454\,\text{gm / lb})}$$

2) Chemical Feed, gpm $\qquad = \dfrac{\text{Chemical Used, gal}}{\text{Length of Application, min}}$

3) Chemical Solution, lbs/gal $= \dfrac{(\text{Chemical Solution, \%})(\text{Sp Gr})(8.34\,\text{lbs / gal})}{100\%}$

4) Feed Pump, gpd $\qquad = \dfrac{\text{Chemical Feed, lbs / day}}{\text{Chemical Solution, lbs / gal}}$

C. Chemical Feeder Setting :

1) Chemical Feed, lbs/day $\quad = (\text{Flow, MGD})(\text{Dose, mg/L})(8.34\,\text{lbs/gal})$

2) Chemical Feeder Setting, mL/min

$$= \dfrac{(\text{Flow, MGD})(\text{Chemical Dose, mg / L})(3.785\,\text{L / gal})(1{,}000{,}000\,\text{gal / MG})}{(\text{Liquid Chemical, mg / mL})(24\,\text{hr / day})(60\,\text{min / hr})}$$

3) Chemical Feeder Setting, gal/day

$$= \dfrac{(\text{Flow, MGD})(\text{Chemical Dose, mg / L})(8.34\,\text{lbs / gal})}{\text{Liquid Chemical, lbs / gal}}$$

4) Chemical Feeder Setting, %

$$= \dfrac{(\text{Desired Feed Pump Rate, gpd})(100\%)}{\text{Maximum Feed Pump Rate, gpd}}$$

IV. COAGULATION AND FLOCCULATION:

1) Polymer, lbs $= \dfrac{(\text{Polymer Solution, gal})(\text{Polymer, \%})(\text{Sp Gr})(8.34\,\text{lbs / gal})}{100\%}$

2) Dose, mg/L $= \dfrac{\text{Chemical Feed, lbs / day}}{(\text{Flow, MGD})(8.34\,\text{lbs / gal})}$

3) Polymer, % $= \dfrac{(\text{Dry Polymer, lbs})(100\%)}{(\text{Dry Polymer, lbs } + \text{ Water, lbs})}$

4) Liquid Polymer, gal $= \dfrac{(\text{Polymer Solution, \%})(\text{Vol of Solution, gal})}{\text{Liquid Polymer, \%}}$

V. FILTRATION:

1) Filtration Flow, gpm $= \dfrac{(\text{Water Drop, ft})(\text{Surface Area, sq ft})(7.48\,\text{gal / ft}^3)}{\text{Time, min}}$

2) Hydraulic Surface Loading Rate, gpm/sq ft $= \dfrac{\text{Flow, gpm}}{\text{Surface Area of Filter, sq ft}}$

   Note: Flow = flow onto the filter

3) Average Hydraulic Surface Loading Rate, gpm $= \dfrac{\text{Total Volume Filtered, gal}}{(\text{Filter Run, hr})(60\,\text{min / hr})}$

4) Peak Hydraulic Surface Loading Rate, gpm/sq ft $= \dfrac{\text{Peak Filter Flow, gpm}}{\text{Filter Area, sq ft}}$

5) Backwash Flow (Using Rise Rate Test), gpm

$= \dfrac{(\text{Filter Surface Area, sq ft})(\text{Rise Distance, ft})(7.48\,\text{gal / ft}^3)}{\text{Rise Time, min}}$

6) Backwash Rate, gpm/sq ft $= \dfrac{\text{Backwash Flow, gpm}}{\text{Filter Surface Area, sq ft}}$

7) Backwash Time, min $= \dfrac{\text{Total Backwash Volume, gal}}{(\text{Backwash Rate, gpm})(\text{Filter Surface Area, sq ft})}$

8) Total Backwash, gal $= (\text{Backwash Flowrate, gpm})(\text{Backwash Time, min})$

9) Backwash, % $= \dfrac{(\text{Total Backwash, gal})(100\%)}{\text{Total Volume Filtered, gal}}$

10) Percent Bed Expansion, % $= \dfrac{(A - C)(100\%)}{B}$

    A = Depth to media as measured from top of sidewall before backwash, inches.*
    B = Media depth (less support gravel), inches.*
    C = Depth to expanded media as measured from top of sidewall during backwash, inches.*

    *Systems should make sure all measurements have the same units.

11) Uniform Filter Run Volume (UFRV)

    UFRV, gal/sq ft $= \dfrac{\text{Volume Filtered, gal}}{\text{Filter Surface Area, sq ft}}$

    gal/sq ft $= (\text{Filter Rate, gpm/sq ft})(\text{Filter Run, hr})(60 \text{ min/hr})$

SAMPLE CALCULATIONS FOR DETERMINING FLOWS AND CHEMICAL DOSES

The following examples demonstrate how the previously presented equations can be used if a system is conducting jar tests or modifying chemical feed practices to improve filter effluent turbidity. Systems may find these examples useful for calculating flow values or determining chemical feed settings.

EXAMPLE 1: Flow Conversion

To convert a flow from gpm to MGD:

Scenario: If a system's flow is 900 gpm and the flow needs to be converted to MGD, the following equation can be used:

$$\text{Flow, MGD} = \frac{(\text{Flow, gpm})(60\,\text{min / hr})(24\,\text{hr / day})}{1,000,000\,\text{gal / MG}}$$

$$= \frac{(900\,\text{gpm})(60\,\text{min / hr})(24\,\text{hr / day})}{1,000,000\,\text{gal / MG}}$$

$$\text{Flow} = \textbf{1.3 MGD}$$

EXAMPLE 2: Chemical Doses

To calculate the liquid alum chemical feeder setting in milliliters per minute:

Scenario: The optimum liquid alum dose based on the jar tests at a particular plant is 12 mg/L. The system wants to determine the setting on the liquid alum chemical feeder in milliliters per minute when the plant flow is 5.3 MGD. The liquid alum delivered to the plant contains 439.8 milligrams of alum per milliliter of liquid solution.

Chemical Feeder Setting, mL/min

$$= \frac{(\text{Flow, MGD})(\text{Alum Dose, mg / L})(3.785\,\text{L / gal})(1,000,000\,\text{gal / MG})}{(\text{Liquid Alum, mg / mL})(24\,\text{hr / day})(60\,\text{min / hr})}$$

$$= \frac{(5.3\,\text{MGD})(12\,\text{mg / L})(3.785\,\text{L / gal})(1,000,000\,\text{gal / MG})}{(439.8\,\text{mg / mL})(24\,\text{hr / day})(60\,\text{min / hr})}$$

Chemical Feeder Setting = **380 mL/min**

EXAMPLE 3: Chemical Dose

To calculate the liquid alum chemical feeder setting in gallons per day:

Scenario: The optimum liquid alum dose based on the jar tests at a particular plant is 12 mg/L. The system wants to determine the setting on the liquid alum chemical feeder in gallons per day when the flow is 5.3 MGD. The liquid alum delivered to the plant contains 4.42 pounds of alum per gallon of liquid solution.

$$\text{Chemical Feeder Setting, gpd} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg/L})(8.34 \text{ lbs/gal})}{\text{LiquidAlum, lbs/gal}}$$

$$= \frac{(5.3 \text{ MGD})(12 \text{ mg/L})(8.34 \text{ lbs/gal})}{4.42 \text{ lbs/gal}}$$

$$\text{Chemical Feeder Setting} = \textbf{120 gpd}$$

EXAMPLE 4: Chemical Dose

To calculate the polymer fed by the chemical feed pump in pounds of polymer per day:

Scenario: A system wants to determine the chemical feed in pounds of polymer per day from a chemical feed pump. The polymer solution contains 18,000 mg polymer per liter. Assume the specific gravity of the polymer solution is 1.0. During a test run, the chemical feed pump delivered 700 mL of polymer solution during 7 minutes.

$$\text{Polymer Feed, lbs/day} = \frac{(\text{Chemical Conc, mg/L})(\text{Vol Pumped, mL})(60 \text{ min/hr})(24 \text{ hr/day})}{(\text{Time Pumped, min})(1000 \text{ mL/L})(1000 \text{ mg/gm})(454 \text{ gm/lb})}$$

$$= \frac{(18,000 \text{ mg/L})(700 \text{ mL})(60 \text{ min/hr})(24 \text{ hr/day})}{(7 \text{ min})(1000 \text{ mL/L})(1000 \text{ mg/gm})(454 \text{ gm/lb})}$$

$$\text{Polymer Feed} = \textbf{5.7 lbs polymer/day}$$

EXAMPLE 5: Chemical Dose

To calculate the flow delivered by the pump in gallons per minute and gallons per day:

Scenario: A small chemical feed pump lowered the chemical solution in a 4-foot diameter tank 1 foot and 3 inches during a 6-hour period.

1. Tank Drop, in feet $= 1 \text{ ft} + \dfrac{3 \text{ in}}{12 \text{ in / ft}}$

   $= 1 \text{ ft} + 0.25 \text{ ft}$

   Tank Drop $= \mathbf{1.25 \ ft}$

2. Determine the gallons of solution pumped.

   Volume Pumped $=$ (Area, sq ft)(Drop, ft)(7.48 gal/cu ft)

   Area $= \pi r^2$
   π $= 3.1416$ (constant)
   r $=$ radius, ft $=$ (diameter / 2) $= 4 \text{ ft}/2 = 2 \text{ ft}$
   Area $= (3.1416)(2 \text{ ft})^2 = 12.5664 \text{ ft}^2$

   Volume Pumped $= (12.5664 \text{ ft}^2)(1.25 \text{ ft})(7.48 \text{ gal/cu ft})$
   Volume Pumped $= \mathbf{117.5 \ gal}$

3. Estimate the flow delivered by the pump in gallons per minute and gallons per day.

   Flow, gpm $= \dfrac{\text{Volume Pumped, gal}}{(\text{Time, hr})(60 \text{ min / hr})}$

   $= \dfrac{117.5 \text{ gal}}{(6 \text{ hr})(60 \text{ min/hr})}$

   Flow $= \mathbf{0.33 \ gpm}$

   OR

   Flow, gpd $= \dfrac{(\text{Volume Pumped, gal})(24 \text{ hr / day})}{\text{Time, hr}}$

   $= \dfrac{(117.5 \text{ gal})(24 \text{ hr / day})}{6 \text{ hr}}$

   Flow $= \mathbf{470 \ gpd}$

EXAMPLE 6: Chemical Dose

To determine the settings in percent stroke on a chemical feed pump (the chemical could be chlorine, polymer, potassium permanganate or any other chemical solution fed by a pump) for various doses of a chemical in milligrams per liter:

Scenario: The raw water flow rate to which the chemicals are delivered is 315 gpm. The solution strength of the chemical being pumped is 3.8 percent. Assume the specific gravity of the chemical solution is 1.0. The chemical feed pump has a maximum capacity of 97 gallons per day at a setting of 100 percent capacity.

1. Convert the raw water flow from gallons per minute to million gallons per day.

    Raw Water Flow, gpd = (Raw Water Flow, gpm)(60 min/hr)(24 hr/day)

    = (315 gal/min)(60 min/hr)(24 hr/day)

    = 454,000 gal/day

    Raw Water Flow = **454,000 gpd = 0.454 MGD**

2. Change the chemical solution strength from a percentage to pounds of chemical per gallon of solution. A 3.8-percent solution means we have 3.8 pounds of chemical in a solution of water and chemical weighing 100 pounds.

    Chemical Solution, lbs/gal $= \dfrac{(\text{Chemical Solution},\%)(8.34\,\text{lbs}/\text{gal})(\text{Sp Gr})}{100\,\%}$

    $= \dfrac{(3.8\,\%)(8.34\,\text{lbs}/\text{gal})(1.0)}{100\,\%}$

    Chemical Solution $= $ **0.32 lbs chemical/gallon solution**

3. Calculate the chemical feed in pounds per day for a chemical dose of 0.5 milligrams per liter. Assume various chemical doses of 0.5, 1.0, 1.5, 2.0, 2.5 mg/L and upward so that if we know the desired chemical dose, we can easily determine the setting (percent stroke) on the chemical feed pump.

    Chemical Feed, lbs/day = (Raw Water Flow, MGD)(Dose, mg/L)(8.34 lbs/gal)

    = (0.454 MGD)(0.5 mg/L)(8.34 lbs/gal)

    Chemical Feed = **1.9 lbs/day**

4. Determine the desired flow from the chemical feed pump in gallons per day.

$$\text{Feed Pump, gpd} = \frac{\text{Chemical Feed, lbs / day}}{\text{Chemical Solution, lbs / gal}}$$

$$= \frac{1.9 \text{ lbs / day}}{0.32 \text{ lbs / gal}}$$

Feed Pump   = **5.9 gpd**

5. Determine the setting on the chemical feed pump as a percent. In this case we want to know the setting as a percent of the pump stroke.

$$\text{Setting, \%} = \frac{(\text{Desired Feed Pump, gpd})(100\%)}{\text{Maximum Feed Pump, gpd}}$$

$$= \frac{(5.9 \text{ gpd})(100\%)}{97 \text{ gpd}}$$

Setting = **6%**

6. Now change the chemical dose in Step 3 from 0.5 mg/L to 1.0 mg/L and other higher doses and repeat the remainder of the steps, to calculate the data in Table 1.

7. Plot the data in Table 1 (Chemical Dose, mg/L vs. Pump Setting, % stroke) to obtain Figure 1. For any desired chemical dose in milligrams per liter, use Figure 1 to determine the necessary chemical feed pump setting.

TABLE 1 - SETTING FOR CHEMICAL FEED PUMP

Pump Flow, GPM   = 315 gpm
Solution Strength, %   = 3.8%

Chemical Dose, mg/L	Chemical Feed, lbs/day	Feed Pump, gpd	Pump Setting, % stroke
0.5	1.9	5.9	6.0
1.0	3.8	11.8	12.2
1.5	5.7	17.8	18.4
2.0	7.6	23.7	24.4
2.5	9.5	29.7	30.6
3.0	11.4	35.6	36.7
3.5	13.2	41.2	42.5
4.0	15.1	47.2	48.7
4.5	17.0	53.1	54.7
5.0	18.9	59.1	60.9
5.5	20.8	65.0	67.0
6.0	22.7	70.9	73.1
6.5	24.6	76.9	79.3
7.0	26.5	82.8	85.4
7.5	28.4	88.7	91.4

FIGURE 1 - CHEMICAL FEED PUMP SETTINGS FOR VARIOUS CHEMICAL DOSES FROM TABLE 1, ABOVE
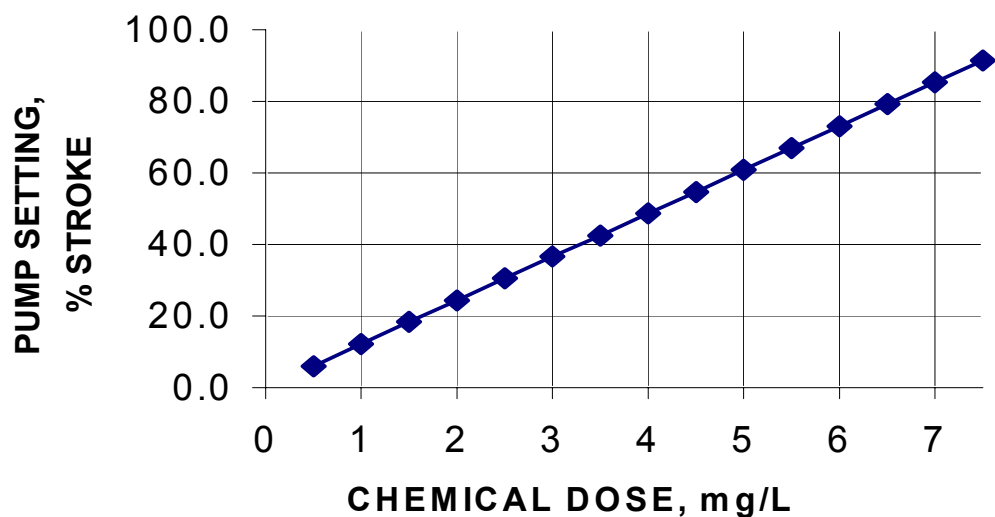
VOLUME EQUATIONS

Water Pipe (raw or treated):
Fluid Volume = Length x Cross-Sectional Area
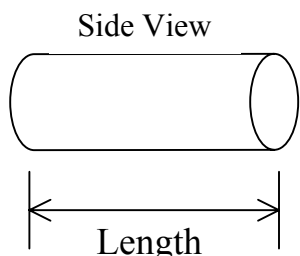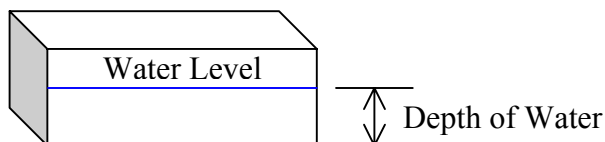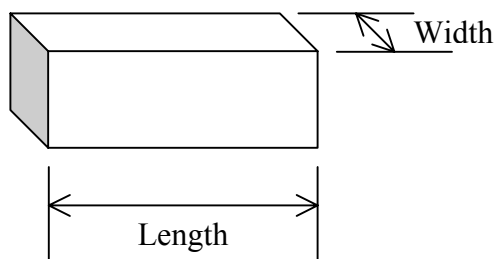
Cross-Section View

Side View

Length

d

r
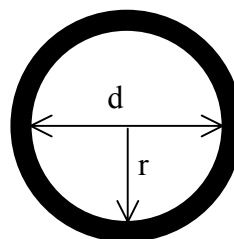
Cross-Sectional Area = $3.1416 * r^2$
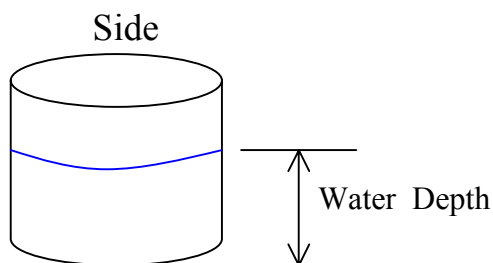r = inner radius = d / 2
d = inner diameter

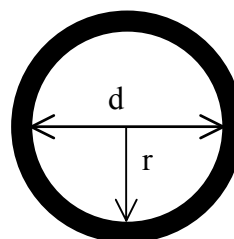**Rectangular Basins:**
Fluid Volume = Length x Width x Depth of Water

Width

Length

Water Level

Depth of Water

Cylindrical Basins:
Fluid Volume = Water Depth x Cross-Sectional Area

Top View

Side

Water Depth

d

r

Cross-Sectional Area = $3.1416 * r^2$
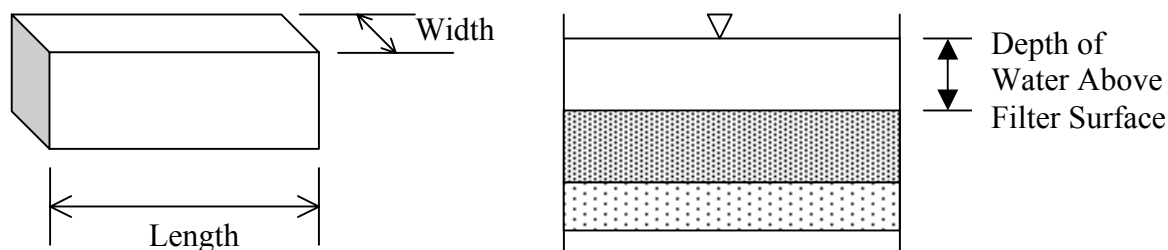r = inner radius = d / 2
d = inner diameter

Filters
Fluid Volume = Volume of Water Above Filter Surface

Fluid Volume = Length x Width x Depth of Water Above Filter Surface

Note: Some States may have other equations to account for the volume in the media.
Check with the State for additional information.

ADDITIONAL RESOURCES

Additional equations, conversions, and examples can be found in the following resources:

- *Small Water System Operation and Maintenance: A Field Study Training Program.*
  California Department of Health Services and USEPA. 1995.

- *Applied Math for Water Plant Operators.* Available at http://www.awwa.org/ and at
  http://www.usabluebook.com.

- *Basic Math Concepts for Water and Wastewater Plant Operators.* Available at
  http://www.awwa.org/ and at http://www.usabluebook.com.

- *Operator Math Made Easy (Video).* Available at http://www.awwa.org/.

Appendix D
Suggested Backwash Rates

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The following tables provide information about backwash rates for different water temperatures and filter media sizes. The properties of water change with temperature.   For instance, water becomes more viscous when it is cold. Particles tend to take longer to sink when the water is cold.

The information in Tables D-1 and D-2 are guidelines for how to adjust the backwash rate based on temperature. These tables should be used with caution because the backwash adjustment rates are general and not site specific. Systems should develop their own site-specific backwash rates based on temperature that provide proper fluidization and bed expansion.

Table D-1 provides guidelines for adjusting the backwash rate to address the change in water properties and to provide a better backwash of the filter. For example, assume the backwash rate is typically 15 gpm/ft^2 (at 71.6°C) during the summer. It is now winter and the wash water temperature is 41°F. Based on the following table, the backwash rate could be adjusted to 12.8 gpm/ft^2. It may not be possible to adjust the backwash rate due to the system configuration. However, if the backwash rate can be adjusted, the suggested backwash rates in the table may enhance the backwashing process.

Table D-2 provides guidelines for determining an appropriate backwash rate for a given temperature and media size. The media size in the table is described by $d_{60\%}$, which is the diameter of the particles the filter media for which 60 percent of the total grains are smaller and 40 percent are larger on a weight basis. Effective size is also commonly used to describe the size of the particles in filter media. The effective size is the particle diameter in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent are larger on a weight basis. If $d_{60\%}$ is not known it can be calculated by multiplying the effective size by the uniformity coefficient of the media. The uniformity coefficient is a media-specific ratio that relates $d_{60\%}$ to the effective size.

Table D-1. Backwash Rate Adjustment for Various Water Temperatures

Wash-Water Temperature (°C)	Wash-Water Temperature (°F)	Water Viscosity (cP)[a]	12 gpm/ft^2 (30 m/h) at 71.6°F (22°C)	15 gpm/ft^2 (37.5 m/h) at 71.6°F (22°C)	18 gpm/ft^2 (45 m/h) at 71.6°F (22°C)	21 gpm/ft^2 (52.5 m/h) at 71.6°F (22°C)
1	33.8	1.728	9.8	12.3	14.8	17.3
2	35.6	1.671	9.9	12.4	14.9	17.5
3	37.4	1.618	10.0	12.6	15.1	17.7
4	39.2	1.567	10.1	12.7	15.2	17.9
5	41.0	1.519	10.2	12.8	15.4	18.1
6	42.8	1.472	10.3	13.0	15.6	18.3
7	44.6	1.428	10.5	13.1	15.7	18.4
8	46.4	1.386	10.6	13.2	15.9	18.6
9	48.2	1.346	10.7	13.4	16.0	18.8
10	50.0	1.307	10.8	13.5	16.2	19.0
11	51.8	1.271	10.9	13.6	16.3	19.2
12	53.6	1.235	11.0	13.8	16.5	19.4
13	55.4	1.202	11.1	13.9	16.6	19.5
14	57.2	1.169	11.2	14.0	16.8	19.7
15	59.0	1.139	11.3	14.1	16.9	19.9
16	60.8	1.109	11.4	14.3	17.1	20.1
17	62.6	1.081	11.5	14.4	17.2	20.2
18	64.4	1.053	11.6	14.5	17.4	20.4
19	66.2	1.027	11.7	14.6	17.5	20.6
20	68.0	1.002	11.8	14.8	17.7	20.8
21	69.8	0.9779	11.9	14.9	17.8	20.9
22	71.6	0.9548	12.0	15.0	18.0	21.1
23	73.4	0.9325	12.0	15.1	18.1	21.3
24	75.2	0.9111	12.1	15.2	18.3	21.4
25	77.0	0.8904	12.2	15.4	18.4	21.6
26	78.8	0.8705	12.3	15.5	18.5	21.8
27	80.6	0.8513	12.4	15.6	18.7	21.9
28	82.4	0.8327	12.5	15.7	18.8	22.1
29	84.2	0.8148	12.6	15.8	19.0	22.2
30	86.0	0.7975	12.7	15.9	19.1	22.4

[a] cP, centipoise.

Reference: Kawamura, Susumu. 2000. Integrated Design and Operation of Water Treatment Facilities, Second Edition. John Wiley & Sons, Inc. New York, NY.

Table D-2. Appropriate Fluidization Backwash Rates

Water Temperature		Fluidization Backwash Rate, gpm/ft^2	
°C	(°F)	Sand ($d_{60\%}$ size of 0.7 mm)	Anthracite Coal ($d_{60\%}$ size of 1.5 mm)
5	41	12	15
10	50	13.5	16.5
15	59	15	18
20	68	16.5	20
25	77	18	22
30	86	20	24

Note: These fluidization backwash rates are guidelines for media with a grain size of $d_{60\%}$ (effective size x uniformity coefficient). The specific gravities are: sand = 2.65 and anthracite coal = 1.65. The rates should be adjusted as necessary for other filter materials. An appropriate fluidization backwash rate is one that fluidizes the bed with adequate expansion and attains sufficient velocities to bring fines to the surface. Fluidization is the upward flow of a fluid through a granular bed at sufficient velocity to suspend the grains in the fluid and depends on filter media properties, backwash temperature, and backwash water flow rates.

Reference: AWWA B100-01.

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Appendix E
Filter Self-Assessment Example Report

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This example of a filter self-assessment report was modified from an example filter self-assessment report created by the Pennsylvania Department of Environmental Protection. The format used in this report is only an example. Before using this format, check with the State to ensure that this format is acceptable.

Filter Self-Assessment
Example Report

Introduction

XYZ Water Treatment Plant was required to perform a filter self-assessment on filter #1 as a result of elevated turbidities over the past 3 months. The Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) requires that a filter self-assessment be conducted for any individual filter that has a measured turbidity level greater than 1.0 nephelometric turbidity units (NTU) in two consecutive measurements taken 15 minutes apart in each of three consecutive months. This report summarizes the findings of our self-assessment on filter #1 and shows our plans to correct the problems that we found.

Filter Self-Assessment Components

The self-assessment of filter # 1 must include the following components:

- An assessment of filter performance;
- The development of a filter run profile;
- Identification and prioritization of factors limiting filter performance; and,
- An assessment of the applicability of corrections.

The factors we investigated are:
- Hydraulic loading conditions of the filter;
- Condition and placement of the media;
- Backwash practices;
- Support media and underdrains; and,
- Rate-of-flow controllers and filter valving.

Assessment of Filter Performance

Filter # 1 is one of four dual media filters at the XYZ Water Treatment Plant. Each filter is 10' x 10' with 100 ft^2 of filter surface area. Each filter is designed to have 20 inches of anthracite and 9 inches of sand. None of the filters are equipped with filter-to-waste capabilities.

Filter Profile

Figure 1 shows a turbidity profile for filter #1. The filter run ended at 80 hours of run time. The filter was then backwashed and placed into service with a turbidity of about 0.56 NTU. Filter #1 then recovered to a turbidity of approximately 0.5 NTU within 3.5 hours. This is not typical of the other three filters at the XYZ Water Treatment Plant. The other filters typically recover to <0.1 NTU within 15 minutes. This is an indication that the problem is within filter #1 and not a result of poor pre-treatment.
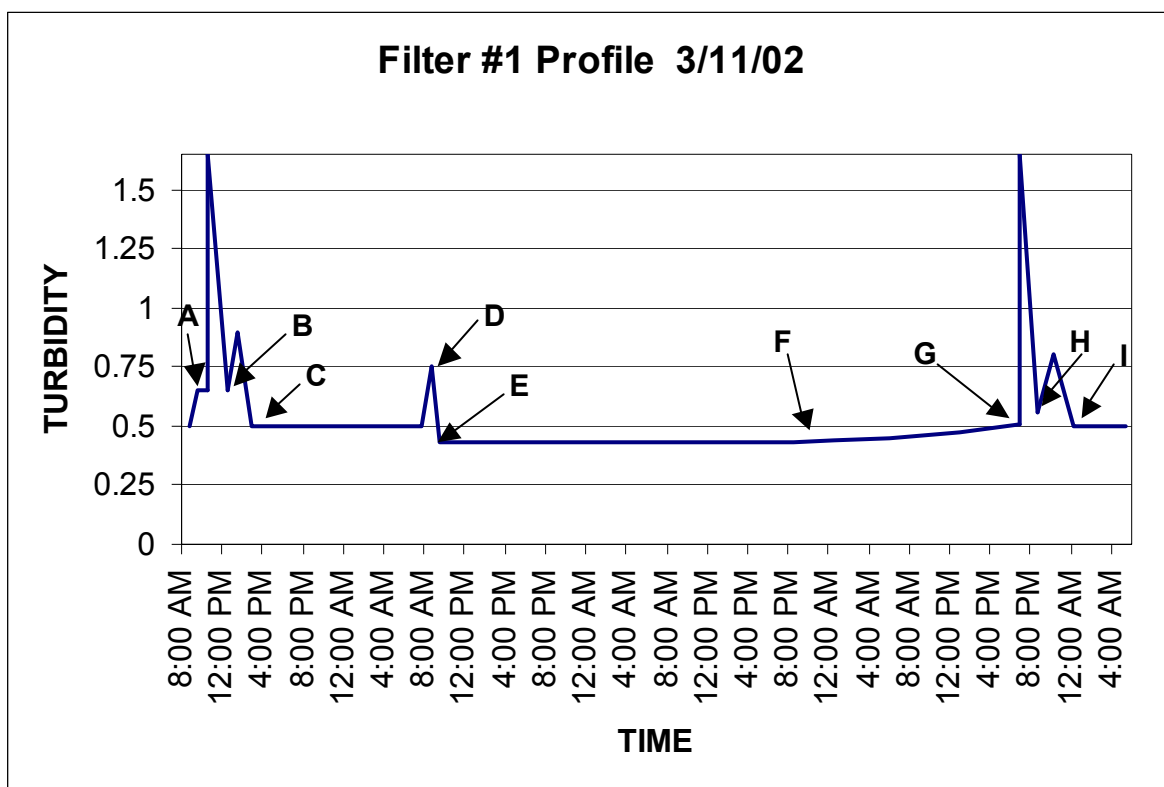
Figure 1. Effluent turbidity profile of filter #1

   A. 10:30 AM Day 1 filter #1 backwashed @ 0.65 NTU
   B. 12:29 PM Day 1 filter # 1 placed into service @ 0.65 NTU
   C. 2:59 PM Day 1 filter #1 recovers @ 0.5 NTU
   D. 8:45 AM Day 2 filter #3 backwashes
   E. 9:30 AM Day 2 performance of filter #1 improves because filter # 3 has been washed which reduces the loading on filter #1
   F. 8:29 PM Day 3 performance of filter #1 begins to degrade
   G. 6:59 PM Day 4 filter #1 backwashed @ 0.51 NTU
   H. 8:44 PM Day 4 filter #1 placed into service @ 0.56 NTU
   I. 12:14 AM Day 5 filter #1 recovers @ 0.5 NTU

Hydraulic Loading Conditions of the Filter

The permitted capacity of XYZ Water Treatment Plant is 1,728,000 gallons/day or 1,200 gpm maximum instantaneous flow rate. This is based on the designed filtration rate of 4 gpm/ft^2 with one filter out-of-service. The plant is always operated at or under 1,200 gpm with the average being 1,100 gpm. In addition, the flow is divided evenly among all filters. When a filter is being backwashed, the flow is divided among the remaining filters, still not exceeding 400 gpm/filter.

Condition and Placement of the Media

The design specifications for the media in all filters are as follows:

<u>Design Media Conditions</u>

<u>Anthracite</u>
effective size	1.0 mm
uniformity coefficient	1.3

<u>Sand</u>
effective size	0.45 mm
uniformity coefficient	1.3

We collected core samples of filter # 1 and had our lab conduct a media analysis according to AWWA Standard B100-01. We found that the current condition of the media is as follows:

<u>Current Media Conditions</u>

<u>Anthracite</u>
effective size	1.3 mm
uniformity coefficient	1.5

<u>Sand</u>
effective size	0.55 mm
uniformity coefficient	1.4

These results show that a coating has developed on our media. The coating is black in color. According to our lab and our media supplier, it is probably a manganese dioxide coating. Our media are 10 years old and we were advised to consider cleaning or replacing the media in the near future.

During the filter inspection there were no signs of surface cracking, mounding of media or separation from the walls. We saw no boiling of media or vortexing. As a result we felt no need to do an extensive inspection of the underdrains. However, mudballs were present on the surface of the filter bed. Inspection of the core samples showed an interface of about 2 to 3 inches between the sand and anthracite.

Our operators also conducted a floc retention analysis as described in *Integrated Design and Operation of Water Treatment Facilities, 2nd edition*, by Susumu Kawamura. The results of the floc retention analysis were 740 NTU/100 grams of media. These results indicate that filter # 1 has mudball problems within the filter media.

While mapping the support gravel, operators found that filter # 1 had only 25 inches of filter media. This is of some concern to us, because we thought that we had 29 inches of media.

Backwash Practices

Filters are backwashed when they reach:
- a terminal head loss >=6 ft
- individual filter effluent turbidity >= 0.3 NTU
- filter run time >=80 hours

The backwash procedures are as follows:
- 5 minutes-filter draw down
- 3 minutes-low wash at 8 gpm/ft^2
- 5 minutes-high wash at 14 gpm/ft^2
- 3 minutes-low wash at 8 gpm/ft^2
- The filter is placed into service after a rest period.

The backwash procedure is programmed into the computer and is not routinely changed. The backwash duration is not extended if the filter is still dirty at the end of the wash.

Backwash rates are limited by the amount of head pressure in the backwash storage tank.

All waste backwash water is sent to the lagoon and then the supernatant is slowly pumped to the sanitary sewer at a rate of 10 gpm. The sludge from the lagoon is cleaned two times per year and the sludge is sent to a landfill.

Our operators built a media expansion tool using a telescopic paint roller pole. A white disk is attached at the end of the pole. The expansion tool is similar to the one used by DEP during filter plant performance evaluations (FPPE) to measure the percent bed expansion. We determined that filter # 1 is getting about 23 percent bed expansion.

Support Media and Underdrains

Our operators mapped the gravel layer using a ½ inch diameter steel rod as described in an AWWA Filter Surveillance video that we purchased for operator training. They found that the gravel layer was within 2 inches of variance. According to Chapter 5 of EPA's *Guidance Manual for Compliance with the Long Term 1 Enhanced Surface Water Treatment Rule: Turbidity Provisions*, the gravel layer should not deviate more than 2 inches. The operators also discovered that we only have a total of 25 inches of filter media. This was verified by digging a test hole and measuring the depth to the gravel layer. Please see figure 2 below for a map of filter #1 support gravel.

Figure 2. Map of filter #1 support gravel in inches below the backwash trough.
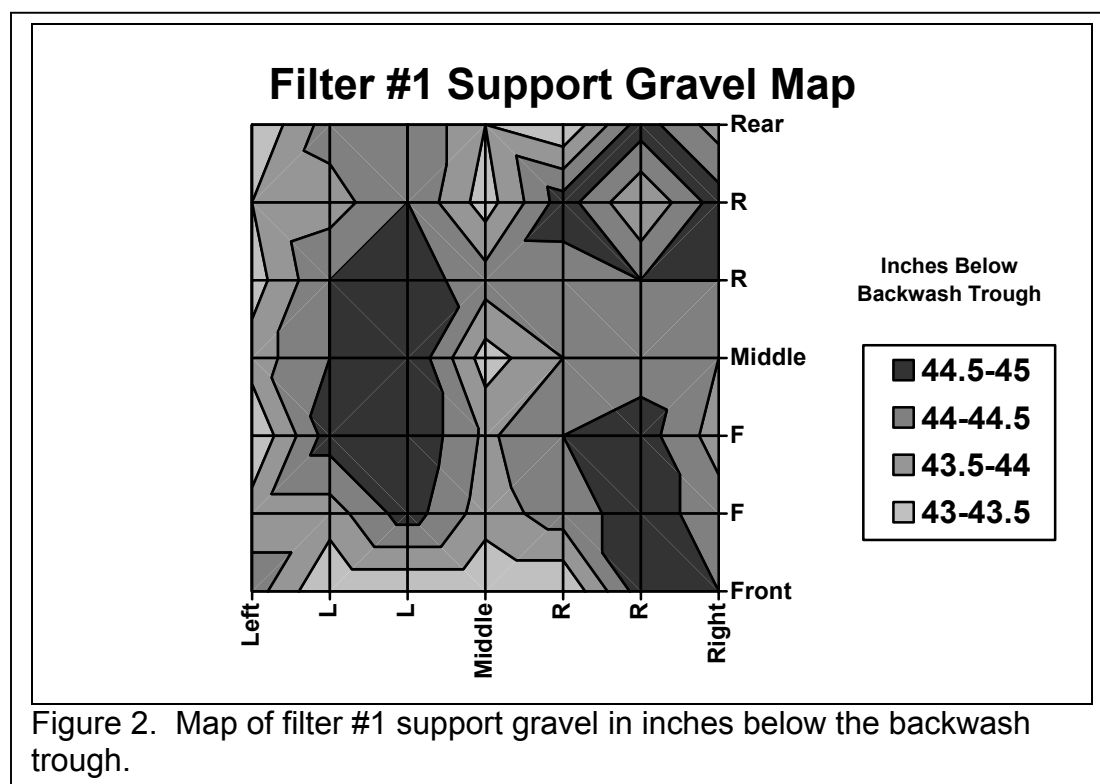
In addition, no media was found in the clearwell, no air boiling was observed during the backwash, and no vortexing was seen while the filter was draining.

Rate-of-Flow Controllers and Filter Valving

No major problems were found with the rate-of-flow control valves or any other valves.

Limiting Factors

Below are the performance-limiting factors identified during the self-assessment of filter #1. These factors are listed in priority order with number one having the highest priority. In addition, each limiting factor has an assessment of the applicability of corrections beneath it. In other words, this is how we determined how effective it would be to correct each limiting factor. We feel that making the corrections listed below will improve the performance of filter #1 and ensure that turbidity excursions over 1 NTU will not occur in the future.

1. **Significant turbidity spike when placing filter #1 into service following backwash. No special procedures for placing a filter into service after backwashing. No filter-to-waste capabilities.**

    Applicability of Corrections: Our plant was designed without filter-to-waste capabilities, otherwise we would be able to send this spike to waste. While reading some filter optimization literature we found a couple of procedures for placing a filter into service after backwashing. The first two that we plan to try immediately are:

    - Allow the filter to rest for one hour before placing it into service; and,
    - Ramp valves open slowly when placing the filter online.

    If these two procedures do not reduce our turbidity spike when placing a filter in service, we will try using a filter aid polymer.

    The addition of filter-to-waste piping has been budgeted into our 3-year plan.

2. **Backwash duration is not extended if the filter is still dirty.**

    Applicability of Corrections: This has already been resolved. Operators have been instructed to observe each backwash. If the water over the filter is still dirty at the end of the high wash, then the high wash is extended until the filter is clean. The time is then programmed into the computer so that the next backwash will automatically be adjusted.

3. **Mudballs on the surface of filter #1. Floc retention analysis results indicate that the filter is still dirty.**

    Applicability of Corrections: Scraping and removing the surface of the filter bed have removed most mudballs. The formation of these mudballs is probably a combination of:
    - Excessive floc carry-over to the filter
    - No surface wash
    - Low filter bed expansion
    - Low backwash rate

- Inadequate backwash duration.

These are all limiting factors that will be addressed independently.

4. **Only 25 inches of media in filter #1.**

   Applicability of Corrections: Filter media is expensive; we feel that topping off the filters with new media now would be a waste of new media, since we plan to rebuild this filter. All media will be replaced within the next 6 months. The filter will then be brought up to the design standard of 20 inches of anthracite and 9 inches of sand.

5. **Manganese dioxide coating on the filter media.**

   Applicability of Corrections: As stated earlier, the filter media will be replaced with all new media within the next 6 months. In addition, we are looking into optimizing our manganese removal in the sedimentation basin. We are planning to move the potassium permanganate feed point upstream to the raw water intake to give more contact time prior to adding our coagulant. We are also planning to add intra-basin baffling to our sedimentation basin and pilot the use of a polymer as a floc aid to help settle our floc in the basin. We plan to have these changes implemented by this winter so that this problem can be resolved before filter #1 has new media. Hopefully these changes will reduce the formation of mudballs and manganese dioxide on the new filter media.

6. **Filter #1 recovers to 0.5 NTU after backwash while other filters recover to 0.1 NTU. Filter #1 turbidity increases significantly when filter # 3 is backwashed.**

   Applicability of Corrections: Although these are two of our greatest concerns, they have received a lower priority because we are uncertain of the cause. Hopefully, this problem will be remedied once the filter is rebuilt. We plan to do a thorough inspection of the underdrains in filter #1 when it gets rebuilt within the next 6 months. This will continue to be a limiting factor that we will stay aware of until the cause is identified and resolved.

Appendix F
Jar Tests

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Jar tests are a valuable tool to determine types and amounts of chemicals to use for optimum floc formation. Jar tests allow a system to experiment with different coagulants, polymers, pH controllers, and oxidants. The jar test should simulate actual plant operating conditions, such as mixing rates and detention times. The information obtained from the jar test can prove invaluable as a system considers different treatment techniques. The most important part of the jar test is to document the procedures used to enable replication in the future. The following worksheets can be used for the jar test. These worksheets are from EPA's Handbook *Optimizing Water Treatment Plant Performance Using the Composite Correction Program, 1998 Edition* (EPA 625-6-91-027). An operator who has never performed a jar test may want to seek technical assistance.

Procedures for the actual jar test are not presented due to the volume of information required. The following references are recommended for detailed instructions for performing a jar test:

- AWWA. 1992. Operational Control of Coagulation and Filtration Processes. M37. American Water Works Association. Denver, Colorado.

- California State University. 1994. Water Treatment Plant Operation, Volume 1. Third Edition. California State University. Sacramento, California.

JAR TEST PROCEDURE (page 1)							
TEST CONDITIONS							
Facility	**Date**	**Time**	**Turbidity**	**Temperature**	**pH**	**Alkalinity**	
Water Source			**Coagulant**		**Coagulant Aid**		

PREPARING STOCK SOLUTIONS	
Step 1	Select desired stock concentration (see Table 1). Choose a stock solution concentration that will be practical for transferring chemicals to jars.

Table 1

Stock Solution (%)	Concentration (mg/L)	mg/L dosage per mL of stock solution added to 2 liter jar
0.01	100	0.05
0.05	500	0.25
0.1	1,000	0.5
0.2	2,000	1.0
0.5	5,000	2.5
1.0	10,000	5.0
1.5	15,000	7.5
2.0	20,000	10.0

Desired Stock Solution (%)	Coagulant	Coag. Aid	

Step 2	Determine chemical amount to add to 1-liter flask. If using dry products, see Table 2. If using liquid products, go to step 3.

Table 2

Stock Solution (%)	Conc. (mg/L)	mg of alum added to 1-liter flask
0.01	100	100
0.05	500	500
0.1	1,000	1,000
0.2	2,000	2,000
0.5	5,000	5,000
1.0	10,000	10,000
1.5	15,000	15,000
2.0	20,000	20,000

Desired Amount In 1-liter flask (mL)	Coagulant	Coag. Aid	

Step 3	Determine liquid chemical amount to add to volumetric flask. For liquid chemicals, use the equation

$$\text{mL coagulant} = \frac{(\text{stock solution \%}) \times (\text{flask volume, mL}) \times (8.34\ lb/gal)}{100 \times (\text{chemical strength, }lb/gal)}$$

	Coagulant	Polymer	
Chemical Strength (lb/gal)[1]			
Stock Solution Volume (mL)			
Desired Volume of Chemical to add to Flask (mL)			

[1] Note: Chemical Strength = chemical density x % strength

JAR TEST PROCEDURE (page 2)							
JAR SETUP							
Set up individual jar doses based on desired range of test. Determine amount of stock solution by dividing doses by mg/L per mL (see Table 1).							
Coagulant – Jar #	1	2	3	4	5	6	
Dose (mg/L)							
Stock Solution (mL)							
Coagulant Aid – Jar #	1	2	3	4	5	6	
Dose (mg/L)							
Stock Solution (mL)							
	1	2	3	4	5	6	
Dose (mg/L)							
Stock Solution (mL)							
TEST PROCEDURE							

Step 1 — Set rapid mix time equal to rapid mix detention time.
To determine rapid mix time, use the following equation -

$$\text{Rapid mix time (min)} = \frac{(\text{rapid mix volume, gal}) \times (1{,}440 \text{ min / day}) \times (60 \text{ sec / min})}{(\text{plant flow rate, gal / d})}$$

Mix Volume (gal)	
Plant Flow Rate (gal/d)	
Mix Time (sec)	

Step 2 — Set total flocculation time equal to total flocculation time in plant.
To determine total flocculation time, use the following equation -

$$\text{Floc time (min)} = \frac{(\text{flocculator volume, gal}) \times (1{,}440 \text{ min / day})}{(\text{plant flow rate, gal / d})}$$

Floc Volume (gal)			
Floc Time (min)			

Step 3 — Use Figure 1* to determine the jar mixing energy values (rpm) that correspond to the approximate flocculator mixing energy values (G). Flocculator mixing energy can be estimated from the plant design information (O&M manual) or can be calculated from the equation described in Appendix F – B.1.Flocculation*.

Flocculator Stage	1st	2nd	3rd	
Flocculator Mixing (G)				
Jar Mixing (rpm)				

Step 4 — Set sample time based on particle settling velocity. Use the equation below to determine sample time when using 2-liter gator jars as described in Figure 1*.

$$\text{Sample time (min)} = \frac{(10 \text{ cm}) \times (\text{surface area, ft}^2) \times (1{,}440 \text{ min / day}) \times (7.48 \text{ gal / ft}^3)}{(\text{plant flow rate, gal / d}) \times (30.48 \text{ cm / ft})}$$

Sedimentation Surface Area (ft²)	
Plant Flow Rate (gal/day)	
Sample Time (min)	

* Figure 1 and Appendix F can be found in *Optimizing Water Treatment Plant Performance Using the Composite Correction Program, 1998 Edition* (EPA 625-6-91-027).

JAR TEST PROCEDURE (page 3)							
TEST RESULTS							
Record test results in the table below.							
	1	2	3	4	5	6	
Settled Turbidity (NTU)							
Settled pH							
Filtered Turbidity (NTU)							
Comments:							

Appendix G
Example of an Operating Procedure for Chemical Feed System

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Following is an example of an operating procedure for the chemical feed practices when raw water turbidity is between 10 and 20 NTU. It may be used as a standard operating procedure (SOP). It is an example and may provide valuable guidelines for systems. However, be careful when conducting any of the procedures contained in the following example operating procedure. Each system is unique and what works well for one system may not work for another. Chemical feed SOPs should be developed based on specific filtered water turbidity goals, jar testing, experience, and other site-specific conditions.

EXAMPLE OPERATING PROCEDURE

Chemical Feed Practices for Raw Water Turbidity Between 10 and 20 NTU[1]

1. Set the alum feed rate at 15 mg/L (metering pump speed at 50 percent speed; do not change the stroke setting).
2. Set the polymer feed rate at 3 mg/L (metering pump speed at 50 percent speed; do not change the stroke setting).
3. Start the plant with clean filters. If filters are not clean, backwash them using SOPs for backwashing.
4. After 20 minutes, note the effluent turbidity readings from the sedimentation basins and from individual filters.
5. The settled water turbidity should be less than 2 NTU.   If turbidity exceeds 2 NTU off of a sedimentation basin, check the individual filter effluent (IFE) turbidities:
    a. If IFE turbidities are less than 0.1 NTU, do not adjust the chemical feed rates.
    b. If IFE turbidities are greater than 0.1 NTU but less than 0.25 NTU, increase the alum feed rate by 5 percent. Wait another 20 minutes to observe.
6. Repeat procedures in Step 5 as necessary.
7. If any of the IFE turbidity readings exceed 0.25 NTU, take the appropriate filter(s) off-line and reduce the flow through the plant by 200 gpm for each filter that is off-line.
8. If IFE turbidity remains between 0.10 NTU and 0.25 NTU after 4 hours of operation, or if a filter(s) is still off-line after 4 hours of operation, call the plant supervisor at 555-5050.
    a. Begin jar testing using alum doses of 10 mg/L, 20 mg/L, 30 mg/L and 40 mg/L.
    b. After results are obtained, run another jar test using alum doses that are slightly above and below the best result from the first test. For example, if the best results were obtained at 30 mg/L, run another set of tests at 26 mg/L, 28 mg/L, 30 mg/L and 32 mg/L.
    c. After the best alum dose is determined from the second jar test, reduce that alum dose by 5 mg/L, and run another set of tests using that alum dose and polymer doses of 2 mg/L, 3 mg/L, 4 mg/L and 5 mg/L. Select the best results from this jar test as the full-scale plant doses for alum and polymer.

IFE Turbidity Goals (for <u>all</u> raw water quality conditions): < 0.10 NTU within 15 minutes of start-up, < 0.10 NTU 95 percent of the time, and always < 0.3 NTU. Raw water turbidity changes should not affect finished water quality.

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1 These procedures assume that:
*   Process control decisions are based upon jar testing results and on past records and experience with similar water conditions.
*   Chemical feed pumps have been calibrated recently.
*   Chemicals have been mixed in accordance with standard practices and manufacturers recommendations.

Appendix H
Example of an Operating Procedure for Filters

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Following is an example operating procedure for backwashing a filter. It may be used as a standard operating procedure (SOP). The following example may provide valuable guidelines for your system. However, be careful when conducting any of the procedures contained in the following example operating procedure to a system. Each system is unique and what works well for one system may not work for another.

EXAMPLE OPERATING PROCEDURE

Filter Backwash[1]

(If the plant is off-line, Step 1 is not necessary. If the plant is on-line, Steps 1 and 2 should be done simultaneously to minimize the effects of flow changes to the filters. Similarly, Steps 18 and 19 should be done simultaneously.)

1. Reduce the flow rate into the plant to prevent increased flow to the other filters.
2. Close the filter influent valve.
3. Close the filter effluent valve when the water level is 6 inches above the media.
4. Disable filter alarms (for example, turbidity and headloss) and shut off flow to the individual filter effluent (IFE) turbidimeter.
5. Allow entrained air to escape from the filter before backwashing (if air is present).
6. Record the filtered water volume from the flow meter (if available).
7. Open the backwash drain valve.
8. Record the backwash water meter reading.
9. Open the surface water supply valve.
10. After the surface washer has run alone for 2 minutes*,* <u>slowly</u> open the backwash water supply valve to the filter. Backwash at 1,000 gpm (10 gpm/ft^2). Hold for 2 minutes. [2]
11. Close the surface water wash supply after it has run for a total of 3 minutes (which includes 1 minute into the backwash cycle).
12. After the filter has backwashed for 3 minutes at 1,000 gpm, *<u>slowly</u>* increase the flow rate to 1,500 gpm (15 gpm/ft^2). Hold for 8 minutes (see 13 below).
13. After backwashing at 1,500 gpm for 8 minutes, or after the effluent turbidity reaches 15 NTU, *<u>slowly</u>* reduce the backwash rate to 1,000 gpm. Hold for 2 minutes.
14. *Slowly* close the backwash valve (over a period of 1 minute).
15. Record the backwash water meter reading.
16. Open the influent valve and slowly fill the filter.
17. Whenever possible, allow the filter to rest for 30 minutes after backwashing.
18. Open the filter-to-waste valve.
19. Increase the flow through the plant to the previous setting.
20. Return flow to the IFE turbidimeter.
21. Filter to waste for 15 minutes or until the IFE is less than 0.1 NTU.
22. Close the filter to waste valve and open the filter effluent valve.
23. Enable filter alarms.
24. Double-check all valve, alarm, and instrumentation settings to make sure that they have been set correctly.

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[1] This example procedure does not include air scour. If air scour is available, the facility should ensure that appropriate steps are added to the SOP.
[2] This example assumes that appropriate backwash rates have been established through experience. In colder climates, backwash rates are typically decreased during cold water conditions because cold water is more viscous. Excessive amounts of anthracite media will be lost into the backwash troughs if the backwash rates are too high for the specific conditions at a facility.